Energy-Economy Relationship And Environmental Regulation In The Presence Of Unrecorded Economy

Fatih Karanfil

UNIVERSITÉ PARIS I – PANTHÉON – SORBONNE

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Fatih KARANFIL

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RELATION ÉNERGIE-ÉCONOMIE ET RÉGULATION ENVIRONNEMENTALE EN PRÉSENCE DE L'ÉCONOMIE NON ENREGISTRÉE

Directeur de thèse :

Katheline Schubert Professeur à l'Université Paris I

JURY :

Olivier Beaumais	Professeur à l'Université de Rouen (Rapporteur)
Mireille Chiroleu-Assouline	Professeur à l'Université Paris I
Ahmet Insel	Professeur à l'Université Galatasaray
Gilles Rotillon	Professeur à l'Université Paris X (Rapporteur)
Katheline Schubert	Professeur à l'Université Paris I

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`I hear and I forget.`
`I see and I remember.`
`I do and I understand.`

Confucius (551 BC-479 BC)

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Introduction générale

> *Every day millions of people make decisions which determine how energy is used. They commute to school and work, produce goods and render services, haul freight, heat their homes and offices. Energy serves as a means to these ends. And the ends define the proper study of energy use and of the CO_2 emissions it generates. Energy consumption has its roots in the ways economies and societies work.*

Dans sa préface au livre «*The link between Energy & Human activity*» de l'Agence internationale de l'énergie (IEA, 1997, p.3), l'ancien directeur exécutif de celle-ci, Robert Priddle, souligne l'importance des différences économiques et culturelles qui jouent un rôle essentiel, d'une part dans la composition de la consommation énergétique, d'autre part dans l'évolution des émissions de dioxyde de carbone (CO_2) qui en résultent. Ces différences déterminent effectivement pour une bonne part les caractéristiques énergétiques et environnementales du fonctionnement économique des pays. Les méthodes et les modèles théoriques et expérimentaux doivent donc être spécifiques et tenir compte autant que possible de ces caractéristiques parmi lesquelles se trouve, par exemple, l'importance des activités économiques non enregistrées.[1] A notre avis, c'est un facteur qui est susceptible d'influencer les résultats

[1] Dans la littérature, plusieurs mots différents peuvent être utilisés pour désigner le même phénomène : par exemple, économie souterraine, non officielle, non structurée ou encore parallèle. Pour une classification détaillée des activités économiques non enregistrées voir Feige (1990).

des études et les propositions de politiques économiques, énergétiques et environnementales qui en découlent. Dans ce contexte, tout en mettant en évidence la présence de ce facteur dans l'économie turque, notre recherche représente une contribution tout à fait originale à la comprehension de la relation trilatérale entre la consommation d'énergie, l'émission de CO_2 et la croissance économique en Turquie, et à la théorie de la régulation environnementale pour les pays où la taille de l'économie non enregistrée est assez grande. Elle implique, par conséquent, une critique des travaux antérieurs sur le sujet qui ne prennent pas en compte ce facteur important.

Dans le reste de cette partie introductive, nous proposons tout d'abord une analyse comparative internationale afin de voir de plus près où se situe la Turquie par rapport à d'autres pays en matière de l'efficacité énergétique de la production et l'efficacité environnementale de la consommation d'énergie. Cette analyse peut aussi nous permettre d'avoir une représentation claire et détaillée de la consommation d'énergie et les émissions de CO_2 d'un grand nombre de pays et leur évolution au cours du temps. Une fois que nous aurons analysé le classement des pays selon les variables considérées, nous exposons l'objet et le plan de cette thèse.

Analyse comparative internationale

Structure et évolution de la consommation d'énergie : convergence ou divergence ?

Le but de cette section est, en utilisant les méthodes statistiques, de fournir une analyse comparative internationale dans le contexte "énergie-croissance-environnement". Les données utilisées pour l'offre de l'énergie primaire rapportée au produit intérieur brut (PIB) ainsi que pour l'émission de CO_2 rapportée à l'énergie consommée sont obtenues des publications de l'Agence Internationale de l'Energie (IEA, 2007a, b, c).

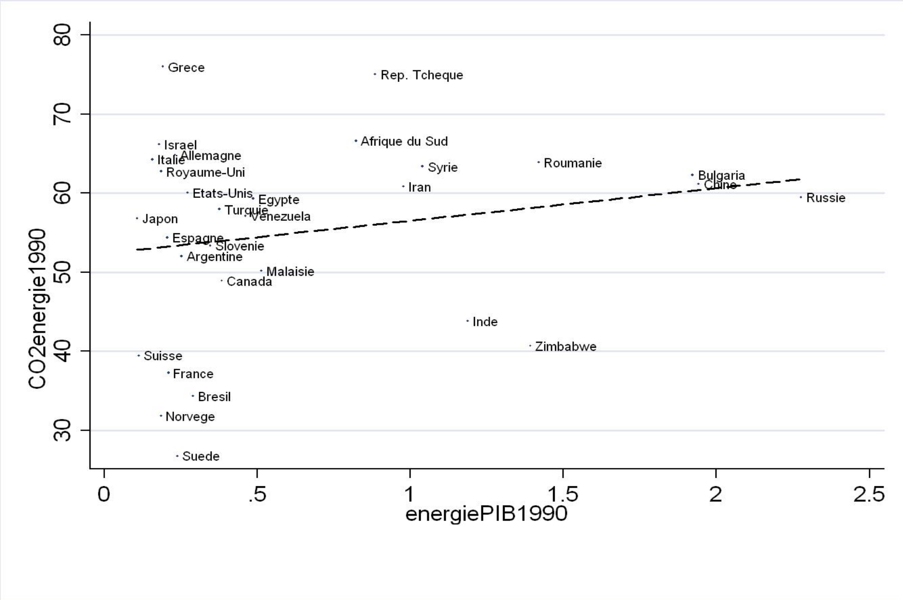

FIG. 1 – En 1990 pour quelques pays choisis, efficacité énergétique dans la production [tonnes d'équivalent pétrole/milliers de dollars (2000 cours fixe)] et efficacité environnementale de la consommation d'énergie [tonnes de CO_2/terajoule (TJ)]. Sources : CO_2 indicators, Energy Balances of OECD countries et Energy Balances of non-OECD countries.

Les Figs. 1 et 2 donnent pour les années 1990 et 2005 respectivement, la distribution de 30 pays selon la consommation d'énergie par unité de production et l'émission de CO_2 par unité d'énergie consommée. Ces deux figures doivent se lire de la façon suivante : si on se déplace vers la gauche sur l'axe des abscisses $energiePIB$, l'efficacité énergétique dans la production augmente et d'autre part, si on se déplace vers le bas sur l'axe des ordonnés $CO2energie$, la consommation d'énergie émet moins de CO_2, en d'autres termes, on utilise davantage des ressources énergétiques plus propres et renouvelables. Dans cette représentation, les pays qui se trouvent en bas à gauche des figures ont les meilleures performances énergétiques et environnementales et les pays en haut à droite sont les mauvais performants.

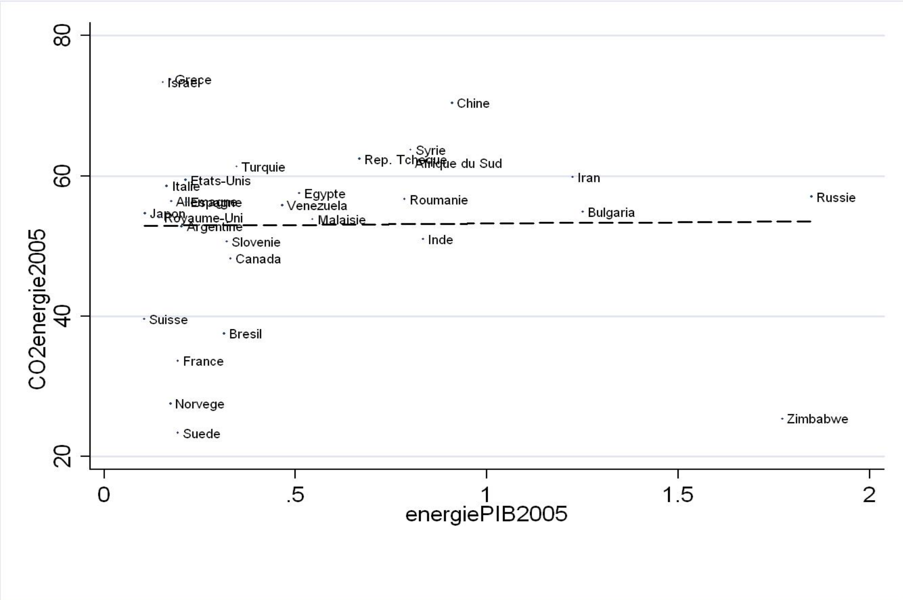

Fig. 2 – En 2005 pour quelques pays choisis, efficacité énergétique dans la production [tonnes d'équivalent pétrole/milliers de dollars (2000 cours fixe)] et efficacité environnementale de la consommation d'énergie [tonnes de CO_2/terajoule (TJ)]. Sources : voir Fig. 1.

Ce que l'on observe tout de suite c'est qu'il n'y a pas beaucoup de changement dans la position des pays au cours d'une période de 15 ans de 1990 à 2005. Par exemple la Grèce, malgré son efficacité énergétique satisfaisante, comme les ressources fossiles sont utilisées extensivement dans le pays, elle a une émission de CO_2 assez élevée qui fait qu'elle a la plus mauvaise performance environnementale parmi ces 30 pays étudiés. Les pays scandinaves et la France (en partie grâce à la production de l'énergie nucléaire), pour ces deux critères, ont les meilleures performances alors que la Russie dans la période considérée est le pays le moins efficient à la fois en matière d'énergie et d'environnement.

D'autre part, bien que la Turquie ait une performance énergétique relativement suffisante, en 2005 elle est le 5ème pays en terme de croissance des émissions de CO_2 par unité énergétique, après la Chine, l'Inde, l'Israël et la Malaisie. Cela montre clairement que les ressources non-renouvelables polluantes sont encore largement utilisées dans le pays.[2]

Nous croyons qu'il faut souligner ici encore un autre point. Dans les pays en voie de développement la taille de l'économie informelle est très grande et donc le PIB *officiel* ne donne pas la taille véritable de l'économie. C'est la raison pour laquelle il faut lire avec précaution les résultats des travaux concernant l'efficacité énergétique dans ces pays.[3]

Dans les Figs. 1 et 2, les lignes en tiret sont les lignes de régression. Avec sa pente positive, la ligne dans le Fig. 1 montre que l'inefficacité énergétique est également liée à l'inefficacité environnementale (l'inverse est aussi vrai). Cette situation est moins remarquable en 2005 (Fig. 2). Une ligne de régression quasi-parallèle à l'axe des abscisses $energiePIB$ avec une distribution des pays sur une échelle plus courte sur l'axe $energiePIB$ donnent déjà un premier signe de convergence dans ce domaine. Une convergence possible de l'efficacité énergétique et/ou environnementale peut être détectée par une analyse plus approfondie pour une période plus longue.

[2] L'étude sur l'utilisation de différentes ressources énergétiques en Turquie constitue l'un des principaux objectifs du premier chapitre. De ce fait, nous ne la discuterons pas dans le cadre de ce chapitre introductif.

[3] Nous présentons une analyse détaillée de ce problème successivement dans les Chapitres 2 et 3.

Pour ce but, nous allons élargir la période considérée à 1971-2005 et augmenter le nombre des pays à 137.[4] La méthode adoptée est de calculer le coefficient de Gini et l'index de Theil qui sont largement utilisés dans la littérature concernant la disparité des revenus.[5] Bien que cette méthode soit apte à estimer l'inégalité dans le "partage d'un gâteau" et qu'il n'y ait pas de problème de distribution dans la question étudiée ici, nous pensons qu'elle peut être utilisée afin de montrer s'il y a une convergence ou divergence entre les pays dans la relation "énergie-croissance-environnement". Il existe, en effet, très peu d'études qui appliquent cette méthode dans les domaines de la consommation d'énergie et des émissions polluantes. A titre d'exemples, nous pouvons citer deux articles : l'un examine la répartition de la consommation d'électricité dans cinq pays : La Norvège, les Etats-Unis, le Salvador, la Thaïlande, et le Kenya (Jacobson et al., 2005) ; l'autre analyse *l'inégalité* des émissions de CO_2 dans 135 pays (Heil et Wodon, 2000).

L'index de Theil est obtenu par la formule suivante :

$$T = \frac{1}{n} \sum_{i=1}^{n} \frac{X_i}{\bar{X}} ln(\frac{X_i}{\bar{X}}) \tag{1}$$

$\bar{X}$ est la valeur moyenne de la variable X (par exemple, offre de l'énergie nécessaire pour une unité de production) et n est le nombre de pays. Si la variable X a la même valeur pour tout pays i (par exemple, au cas où l'efficacité énergétique est la même dans tous les pays), on a $X_i = \bar{X}$ et comme $ln(\frac{X_i}{\bar{X}}) = ln1 = 0$, on obtient $T = 0$. Dans un autre cas extrême, si la valeur prise de la variable X pour un autre pays j, $X_j \neq 0$ et qu'elle est nulle pour tout autres pays (i.e. plus formellement, si $\forall i \neq j$,

[4]Pour la période 1971-1989 le nombre des pays étudiés est de 117 alors qu'il est de 137 après la chute de l'Union soviétique.

[5]Nous tenons à remercier Sezgin Polat pour ses conseils sur l'aspect méthodologique de cette section.

$X_i = 0$), dans ce cas là on a $T = ln(n)$. Cette situation est évidemment n'est pas possible pour le problème qui nous intéresse dans la présente étude. En conséquence, les valeurs minimum et maximum que l'index de Theil peut avoir peuvent s'écrire comme $T \in [0, ln(n)]$. On dirait qu'il s'agit d'une convergence si la valeur de cet index s'approche de 0 et d'une divergence si elle s'approche de $ln(n)$.

Pour obtenir le coefficient de Gini, la formule utilisée est donnée ci-dessous.

$$G = \frac{2}{\bar{X}n^2} \sum_{i=1}^{n} (s_i - \frac{n+1}{2}) X_i \qquad (2)$$

En plus des paramètres utilisés pour le calcul de l'index de Theil, il y a ici une autre variable, s_i, qui est le rang du pays i parmi n pays pour la variable X. Cela veut dire que pour une variable X (par exemple émission de CO_2 par une unité d'énergie) le pays qui a la valeur la plus élevée a $s_i = 1$, alors qu'on note $s_i = n$ pour le pays qui a la plus petite valeur. Si on fait des démonstrations similaires aux celles faites pour l'index de Theil on obtient $G \in [0, 1]$. Comme c'était le cas pour l'index de Theil, une diminution du coefficient de Gini peut se traduire par une convergence et une augmentation de ce dernier donne une divergence.

Les Figs. 3 et 4 donnent respectivement pour l'efficacité énergétique du processus productif et pour l'efficacité environnementale de la consommation d'énergie l'index de Theil et le coefficient de Gini qui sont calculés par les formules données dans les Eqs. (1) et (2). Dans ces deux figures, on remarque une tendance à la baisse à la fois du coefficient de Gini et de l'index de Theil (i.e. existence d'une convergence). Le trend à la baisse dans l'efficacité énergétique est plus évident que celui dans l'efficacité environnementale. Nous constatons également plus de fluctuations conjoncturelles dans l'efficacité énergétique. Le pic en 1990 peut être expliqué par le fait qu'après la chute de l'Union soviétique les nouveaux pays émergents ont adopté

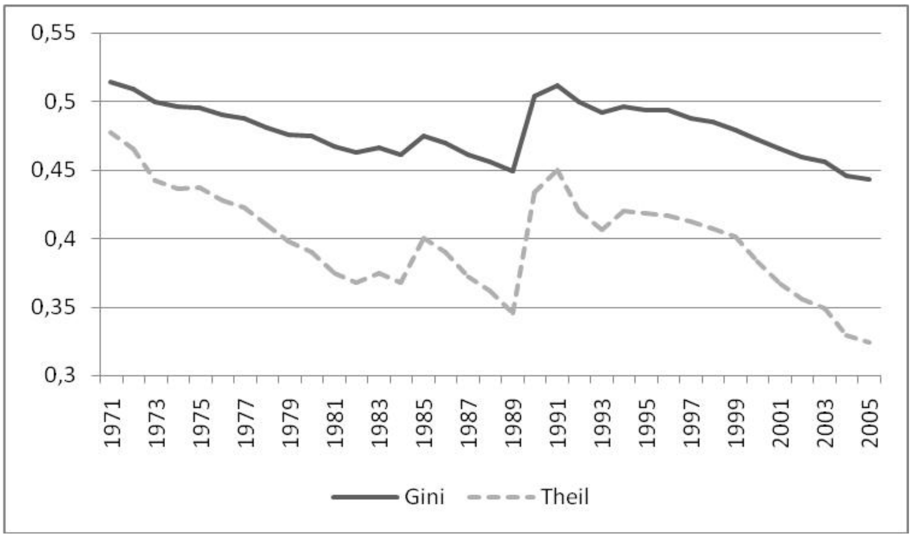

Fig. 3 – Coefficient de Gini et Index de Theil (pour une unité de PIB l'offre d'énergie nécessaire).

une stratégie de développement utilisant extensivement les ressources énergétiques dont ils disposaient.[6] D'autre part, dans la Fig. 4, la baisse régulière (*smooth*) des variables considérées peut être expliquée par le fait qu'il n'est pas facile de substituer les énergies fossiles par les énergies renouvelables (*fuel switching*).

Un autre résultat des Figs. 3 et 4 c'est que les valeurs prises par le coefficient de Gini et l'index de Theil sont plus élevées pour l'efficacité énergétique que pour l'efficacité environnementale. Autrement dit, lorsque la quantité d'énergie nécessaire pour produire une unité de PIB est considérée comme une variable explicative, les pays se distinguent davantage. Cette observation peut être expliquée par la différence des niveaux technologiques et la répartition sectorielle des activités économiques

[6]Il faut également préciser qu'il est possible qu'il y ait eu dans ces pays, de gros problèmes dans la mesure des indicateurs économiques y compris la consommation d'énergie, ce qui peut créer ce pic en 1990.

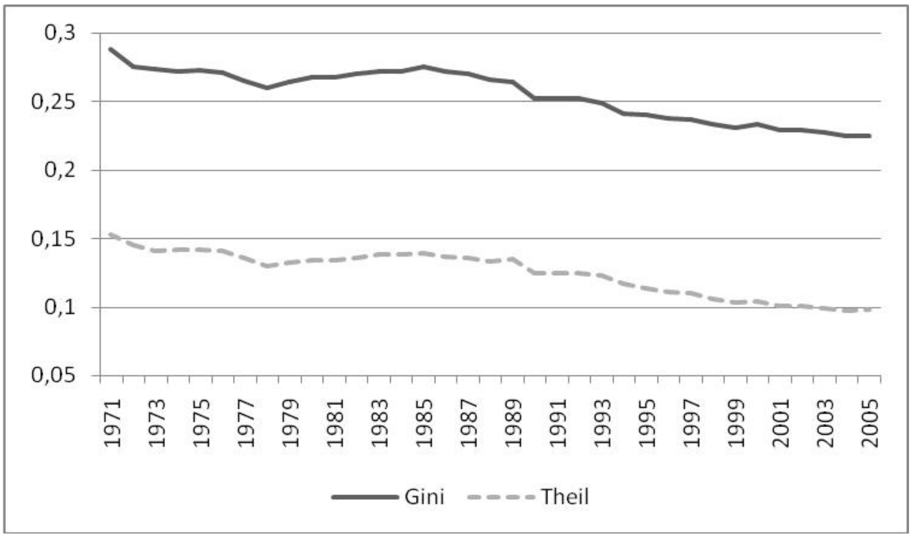

FIG. 4 – Coefficient de Gini et Index de Theil (pour une unité de l'offre d'énergie la quantité de CO_2 émise).

dans ces pays.

Celui qui interprète les résultats obtenus par le coefficient de Gini et l'index de Theil doit se demander bien entendu la direction de la convergence. Est-ce que par exemple les pays ayant une émission forte de CO_2, en adoptant des technologies propres ou bien en diminuant la part des ressources fossiles dans la consommation totale d'énergie, convergent vers les pays qui émettent relativement moins de CO_2, ou bien est-ce l'inverse qui est vrai ? Pour donner une réponse satisfaisante à cette question, il suffit de calculer l'évolution de la moyenne des variables analysées.[7]

Nous voyons aisément que malgré quelques *légères* fluctuations, pour une période de 35 ans le niveau des variables est resté stable (Fig. 5). Compte tenu de ce que nous avons dit jusqu'ici, nous pouvons citer les deux conclusions suivantes : primo,

[7]Pour une approche plus courante sur la convergence et divergence des pays, voir par exemple, Sala-i-Martin (1996).

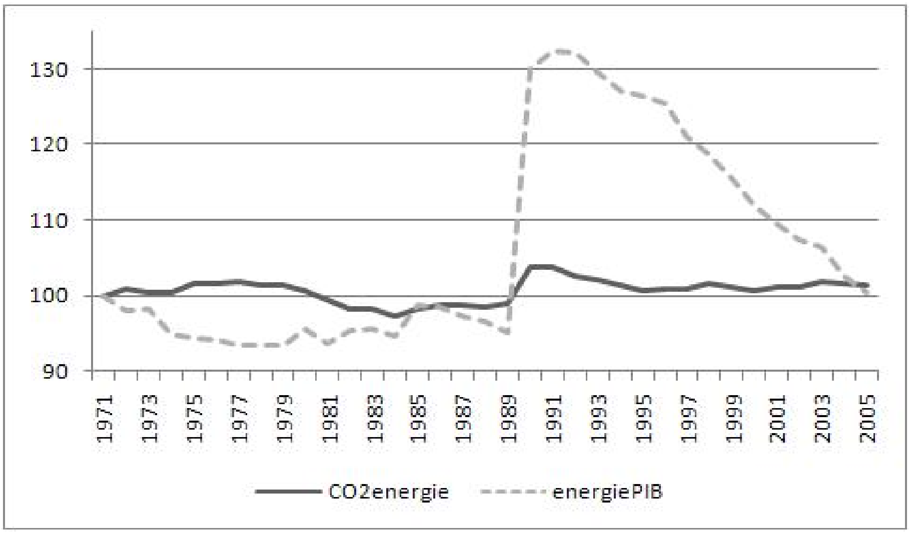

Fig. 5 – Efficacité énergétique de la production et efficacité environnementale de la consommation d'énergie (1971=100). Sources : voir Fig. 1.

les pays qui consommaient davantage d'énergie avant ont diminué relativement leur consommation d'énergie (passage à l'utilisation intensive d'énergie) alors que dans les pays qui consommaient peu d'énergie au début, l'utilisation énergétique a augmenté (l'usage extensif d'énergie) ; secundo, les pays émettant davantage de CO_2 (les pays industrialisés) ont accru leurs efforts d'abattement pour diminuer leurs émissions de gaz à effet de serre alors que les pays en voie de développement ont lié leur développement et croissance économique à l'utilisation extensive des ressources énergétiques sans prendre en compte les externalités négatives liées à la consommation des ressources non renouvelables, d'où une croissance des émissions de CO_2 dans ces pays. Nous devons également préciser que la baisse brutale de l'efficacité énergétique en 1990 (i.e. une hausse brutale du ratio *énergie/PIB*) est produite pour l'une des raisons que nous avons citées ci-dessus.

Index d'énergie-croissance-environnement

Les analyses suivies dans la section précédente ont clairement montré qu'il s'agit des trends de convergence différents selon l'efficacité énergétique et environnementale. Cependant cette analyse utilisant le coefficient de Gini et l'index de Theil ne donne que des ratios qui ne peuvent pas servir à une étude au niveau national. C'est la raison pour laquelle une autre méthode est indispensable, non seulement pour analyser l'évolution au cours du temps de l'efficacité énergétique et environnementale de chaque pays séparément, mais également, en réduisant à une seule variable les informations données par ces deux variables, pour obtenir un index général de "énergie-croissance-environnement". Nous proposons une approche très pédagogique et facile à comprendre que constitue une technique d'indexation utilisant l'équation suivante :

$$E_{X_i}^t = \frac{X_i^t - X_{Min}^t}{X_{Max}^t - X_{Min}^t} \tag{3}$$

Ici $E_{X_i}^t$ donne dans l'index E la valeur prise du pays i en année t pour la variable X. X_{Max}^t et X_{Min}^t sont respectivement les valeurs maximum et minimum que la variable X prends parmi tous les pays. Pour une variable quelconque, Eq. (3) donne en numérateur, la distance entre le pays i et le pays dont la valeur prise est la plus petite, et en dénominateur, la différence entre la plus grande et la plus petite valeur. Cela veut dire que tous les pays sont distribués dans un intervalle entre 0 et 1 et que le pays qui a la meilleure performance (i.e. le pays dont le ratio *énergie/PIB* ou CO_2*/énergie* est le plus petit) a 0, alors que le pays qui est le moins efficient a 1 dans cet index. Encore plus formellement, nous pouvons écrire : $E_{X_i}^t \in [0, 1]$.

En utilisant cette méthode pour les variables dont nous disposons, nous avons construit trois différents index : un premier pour l'efficacité énergétique de la consommation d'énergie (*énergie/PIB*) ; un deuxième pour l'efficacité environnementale de la consommation d'énergie (CO_2/*énergie*) ; et finalement un index général qui est une composition de ces deux premiers index. Lorsque l'on construit l'index général, pour additionner les valeurs prises de chaque pays dans les deux autres index, il faut faire une pondération. Nous avons choisi de faire une pondération égalitaire (i.e. 50% pour l'efficacité énergétique et 50% pour l'efficacité environnementale). On peut bien entendu considérer d'autres configurations ; par exemple, un chercheur qui donne davantage d'importance à l'aspect environnemental de la consommation d'énergie peut décider de donner, dans l'index général, un poids de 70% à l'efficacité environnementale et en conséquence un poids de 30% à l'efficacité énergétique.

Les résultats de cette analyse sont rapportés dans les tableaux présentés en annexe de ce document. Si nous regardons le Tableau 5.4 qui donne l'index de l'efficacité énergétique, nous constatons bien que le rang de la Turquie est stable et elle se trouve au 49ème rang parmi 132 pays. La Turquie a ainsi une performance meilleure que plusieurs pays de l'OCDE tels que la Pologne, la République tchèque ou encore le Slovaquie. Par contre, elle se trouve au dessous des pays industrialisés ainsi que d'autres pays tels que Pérou, Argentine et Uruguay. Il n'est pas surprenant de voir les pays tels que Hong Kong et la Suisse d'avoir les meilleures performances énergétiques puisqu'une grande partie de la valeur ajoutée créée dans ces pays vient des secteurs financiers et tertiaires. D'autre part, avec quelques pays d'Afrique, les pays ex-soviétiques se trouvent en bas de l'index.

En ce qui concerne l'index de l'efficacité environnementale (voir Tableau 5.5), la performance de la Turquie est relativement plus mauvaise, car elle se trouve au 112ème et au 110ème rang en 2000 et en 2005 respectivement. Plusieurs pays de l'OCDE comme Irelande, Grèce et Australie se trouvent au dessous de la Turquie, en revanche beaucoup de pays en voie de développement ont une performance environnementale meilleure que celle de la Turquie. L'utilisation relativement faible des ressources fossiles dans les pays d'Afrique fait que ces pays se trouvent en haut de l'index.

Finalement quand nous regardons le Tableau 5.6 qui donne l'index général de "énergie-croissance-environnement", nous voyons que la Turquie a des rangs différents selon l'année considérée ; plus exactement elle est en 78ème, 99ème et 86ème positions en 1990, 2000 et 2005 respectivement. Avec cette performance nous pouvons classer la Turquie dans le groupe des pays à performance moyenne-basse.

L'objet et le plan de la thèse

Paul Zagamé, dans l'ouvrage qu'il a dirigé avec Katheline Schubert «*L'environnement-Une nouvelle dimension de l'analyse économique*», exprime l'importance et la nécessité d'effectuer davantage de recherche dans le domaine de l'économie de l'environnement en ces termes :

"*Dans les faits, si l'on ne peut encore sonder les cœurs et les reins des Etats et leur engagement profond dans les questions écologiques, notre profession est déjà très sollicitée pour mieux intégrer la dimension environnementale à son analyse et aux recommandations de politique économique.*" (Schubert et Zagamé, 1998, p. 1).

Il ne fait pas de doute que depuis la révolution industrielle, le mode de croissance de l'économie mondiale n'a pas un caractère soutenable. D'une part le fait que les facteurs énergétiques utilisés dans la production sont en grande partie des ressources non-renouvelables (i.e. des ressources épuisables), et d'autre part le réchauffement climatique causé par l'utilisation extensive des ressources fossiles, qui constituent la source principale des émissions de CO_2, mettent en difficulté l'économie des pays et *compromettent la capacité des générations futures à satisfaire leurs besoins*[8]. C'est dans cette perspective que par le protocole de Kyoto, signé le 11 décembre 1997 et entré en vigueur le 16 février 2005, les pays ayant ratifié ont accepté de diminuer les concentrations de gaz à effet de serre dans l'atmosphère.

Presqu'en parallèle de ces développements, la littérature de l'économie de l'énergie et de l'environnement s'est considérablement enrichie de diverses recherches dont le nombre (et grâce aux nouvelles techniques, la qualité) a sensiblement augmenté. Ces recherches débouchent sur des recommandations de politique économique en matière de consommation d'énergie et règlementation environnementale. Les articles de cette littérature ont suivi principalement deux axes : empirique et théorique. La recherche présentée dans cette thèse se situe également sur ces deux axes essentiels.

Au cours de nos recherches empiriques, les problèmes que nous nous sommes successivement posés, et que nous avons étudiés, sont ceux-ci : En Turquie quelles sont les principales caractéristiques de la consommation d'énergie (i.e. part des ressources fossiles et des énergies renouvelables) au niveau national et sectoriel ? Que peut-on en déduire en ce qui concerne les émissions de CO_2 ? Bien qu'il ne fasse pas de doute que ces émissions de CO_2 sont le principal responsable du réchauffement climatique, est-ce qu'il n'y a pas un moyen, de *s'en servir* à des fins de recherche sur l'estimation d'une variable purement économique qui est la taille de l'économie non enregistrée ? Si les activités économiques non enregistrées représentent une part non négligeable dans l'ensemble de l'économie, est-ce que prendre en compte de la taille

[8]La définition la plus souvent avancée du développement durable est due au rapport Brundtland (WCED, 1987) qui énonce que "le développement durable est un développement qui répond aux besoins du présent sans compromettre la capacité des générations futures de répondre aux leurs".

Tab. 1 – Une comparaison des travaux antérieurs sur la causalité entre la consommation d'énergie et la croissance économique en Turquie

Travaux	Période	Méthode	Résultat*
Soytas et Sari (2003)	1950-1992	Modèle à correction d'erreurs (ECM)	Ener.→ Eco.
Altinay et Karagol (2004)	1950-2000	Tests de causalité	Ener.× Eco.
Lise et Montfort (2007)	1970-2003	Moindres carrés ordinaires et ECM	Ener.← Eco.

*Ener. et Eco. indiquent consommation d'énergie et croissance économique, respectivement. ← et → dénotent les directions de causalité. × montre qu'il n'existe pas de causalité.

de l'économie non enregistrée modifie les résultats des investigations sur la relation de long terme entre la consommation d'énergie et la croissance économique ?

Depuis l'article pionnier de Kraft et Kraft (1978) de nombreux travaux ont eu pour but d'examiner la relation d'équilibre de long terme entre la croissance économique et la consommation d'énergie. De plus, s'il existe une telle relation, la détermination de la direction de causalité entre ces deux variables était un autre objectif principal de ces recherches empiriques. Cependant la majorité de ces travaux a rapporté des résultats inconsistants. Les résultats des travaux antérieurs sur la Turquie sont présentés dans le Tableau 1. Les trois raisons le plus souvent invoquées pour ces résultats conflictuels sont : (1) le pays étudié, (2) la méthodologie employée et (3) la période considérée. Le premier chapitre s'efforce alors particulièrement de présenter une vision éclairante des questions relatives au développement économique, à l'évolution de la consommation énergétique et enfin, sur la base d'une analyse économétrique de séries temporelles, à l'existence d'une relation de causalité entre deux variables ; le produit national brut (PNB) et la consommation d'énergie au niveau national et industriel en Turquie pour la période 1963-2003. Dans ce Chapitre 1, comme dans l'ensemble de cette thèse, nos analyses économétriques suivent les étapes habituelles des études de séries temporelles qui peuvent être résumées en trois points : (1) tester la stationnarité des variables en appliquant les tests de racine unitaire de Dickey-Fuller (Dickey et Fuller, 1981) et de Phillips-Perron (Phillips et Perron, 1988), (2) en utilisant l'approche de Johansen et Juselius (1990), montrer s'il existe une relation de cointégration entre les variables étudiées et finalement (3) appliquer le test de Granger (1969) pour estimer la direction de causalité. Certes, les tests fondamentaux que nous évoquons ici sont les plus importants, mais il en existe bien d'autres qui seront abordés dans les sections méthodologiques de chaque chapitre. Toujours dans ce premier chapitre, des estimations économétriques ont également été réalisées en écrivant les modèles en variables par tête, de manière à tenter de voir s'il y a une différence entre les résultats de deux sortes de modèles. De plus, en utilisant un modèle autorégressif à retards distribués (ARDL), nous analyserons la relation de long terme entre les activités économiques et différentes ressources énergétiques, à savoir charbon, pétrole, électricité et gaz naturel. Ensuite nous allons passer de l'analyse sur la relation énergie-économie à l'analyse sur la liaison environnement-économie et donc nous finirons ce premier chapitre par une estimation d'une courbe de Kuznets environnementale pour les émissions de CO_2 en Turquie.

Bien que l'évolution macroéconomique en relation avec la consommation énergétique en Turquie soit bien présentée, à notre avis, le reste du premier chapitre (c.-à-d. les estimations économétriques sur la relation energie-economie) doit être réévalué, puisque cette étude ne s'intéresse pas au caractère spécifique des économies des pays en voie de développement qui est l'existence des activités économiques non enregistrées, non observées ou encore non mesurées dans le calcul de leur PIB *officiel*. C'est la raison pour laquelle, non seulement pour compléter notre analyse et affiner notre vision sur la relation entre la croissance économique et la consommation d'énergie mais également, pour soulever des questions relatives à l'interaction entre la politique de l'énergie et de l'environnement et la taille de l'économie non enregistrée, qui seront approfondies dans les chapitres suivants, il faut une analyse plus détaillée et plus poussée prenant en compte les activités économiques non mesurées dans le calcul officiel du PIB de la Turquie.

D'ailleurs en Turquie, les autorités économiques et politiques sont à l'heure actuelle tout à fait conscientes de l'importance de la taille de l'économie non enregistrée, de la nécessité de prendre en compte les activités dans cette économie et donc de la défaillance du système de comptabilité existant utilisé pour le calcul du PIB. Cette prise de conscience est devenue effective avec la volonté de s'adapter au nouveau système européen des comptes nationaux et régionaux (SEC 95). Avant on utilisait le système de comptabilité nationale des Nations Unies (SCN 68).[9] En conséquence, on remarque que la difference antre la nouvelle serie révisée de PIB (qui remonte jusqu'en 1998) et l'ancienne série varie entre 26 et 37 pour cent de cette dernière. Cette réévaluation officielle est due en très grande partie à l'intégration des activités économiques non enregistrées dans le calcul du PIB. Pour ce faire, dans l'estimation de la nouvelle série, les flux intersectoriels (surtout entre l'industrie et la construction) sont pris en compte, les nouveaux produits agricoles et animaux sont

[9] En adoptant ce nouveau système des comptes nationaux l'Eurostat vise à harmoniser la méthodologie, préciser les concepts, les définitions et les classifications pour obtenir une description quantitative cohérente, fiable et comparable des économies des pays de l'Union. Toute information complémentaire peut être obtenue sur le site internet de CIRCA (Communication and Information Resource Centre Administrator) via http ://circa.europa.eu/irc/dsis/nfaccount/info/data/ESA95/fr/esa95FR.htm.

inclus, les enquêtes sur la force de travail sont aussi utilisées (par exemple, pour l'année 2002 l'emploi enregistré dans l'industrie de tranformation était de 2,133,644, alors que selon les résultats de l'enquête sur la force de travail, il est de 3,545,163), d'autres activités économiques (par exemple, services à la personne, sécurité, nettoyage, jardinage, etc.) sont également inclues dans le nouveau système.

Nous allons donc répondre à cette dernière critique en proposant, dans le troisième chapitre, une analyse sur la relation entre la consommation d'énergie et la croissance économique à la fois officielle et non enregistrée. Mais avant de le faire, il est bien évidemment nécessaire d'estimer la taille de l'économie non enregistrée.

Il existe dans la littérature de nombreuses méthodes utilisées dans l'estimation de la taille de l'économie non enregistrée. Parmi celles-ci, nous pouvons citer, entre autres, l'approche de la demande de monnaie (Cagan, 1958), l'approche de transaction (Feige, 1979) ou encore l'approche économétrique (Tanzi, 1983). Cependant, la plupart d'entre elles ont des points forts et des points faibles.[10] Le deuxième chapitre de cette thèse est une contribution essentielle à l'estimation de la taille de l'économie non enregistrée où nous proposons une méthode inédite par rapport aux études existantes. Pour dire les choses simplement, notre intuition est que le niveau des émissions de CO_2 peut être un bon indicateur du niveau d'activité économique dans le pays. Après une étude économétrique sur les variables (émissions de CO_2, population, PIB officiel et la surface des forêts), nous appliquons le filtre de Kalman pour estimer le *vrai* PIB, qui est la somme de toute activité économique enregistrée et non enregistrée. Nous pouvons alors passer à l'étape suivante celle de la réinvestiga-

[10]Dans l'introduction du deuxième chapitre, nous proposons une description détaillée de toutes les méthodes d'estimation dans la littérature concernant les activités économiques non enregistrées. Pour plus d'information, le lecteur intéressé peut se référer à Thomas (1999).

tion de la relation et la causalité entre la croissance économique et la consommation d'énergie.

Avant de commencer notre étude économétrique présentée dans le troisième chapitre de cette thèse, nous avons réfléchi à une question très importante : dans des tests de cointegration et de causalité avec la consommation d'énergie, si nous utilisons la série du *vrai* PIB estimée dans le deuxième chapitre, seront-ils fiables les résultats d'une telle analyse ? Bien que l'estimation de la taille de l'économie non enregistrée en utilisant les variables environnementales soit une technique très prometteuse, ses résultats ne sont pas appropriés pour une analyse économétrique avec la consommation d'énergie, parce que ces deux séries sont *a fortiori* corrélées. Nous discutons en détail, dans la deuxième section du troisième chapitre, pourquoi nous en venons à cette conclusion et donc ne travaillons pas avec le *vrai* PIB du deuxième chapitre. Dans ce cas, afin d'effectuer les analyses que nous avons en tête, les tests économétriques sur la relation entre la consommation d'énergie et la croissance économique sont réalisés en utilisant la taille de l'économie non enregistrée en Turquie estimée par Savasan (2003) et Schneider et Savasan (2007). Car nous croyons que, parmi d'autres méthodes existantes, la méthode utilisée dans ces travaux, qui est connue sous le nom de "*multiple indicator multiple causes (MIMIC) model*" (Goldberg, 1975 ; Frey et Weck, 1983a, b, 1984), donne les résultats les plus fiables, parce qu'elle considère à la fois les causes de l'économie non enregistrée (telles que le taux de chômage, le taux d'inflation, etc.) et ses impacts sur la production, le marché du travail et de la monnaie. Notre analyse est effectuée d'abord en utilisant un modèle sans économie non enregistrée. Puis sont discutés et analysés l'introduction dans le modèle, des activités économiques non enregistrées et les effets qu'elle a sur les résultats de l'analyse précédente. A notre avis, le problème de l'existence d'une relation énergie-économie posé de cette manière est la deuxième contribution essentielle de cette thèse de doctorat, au moins sur le plan de la réflexion empirique.

Nous voyons que les trois premiers chapitres sont consacrés à une réflexion sur tous les aspects des questions posées au début de cette section alors que les conséquences qui en découlent en matière de politique économique, énergétique et environnementale vont servir à établir certains éléments du cadre théorique de notre deuxième partie de la recherche dont la problématique se noue autour de quelques questions clés qui peuvent être formulées comme suit : Les principales recommandations que nous proposons dans ces trois premières chapitres, sont fondées sur le fait qu'il existe en Turquie, comme dans beaucoup d'autres pays en voie de développement, une économie non enregistrée assez étendue et qu'une politique environnementale peut avoir des effets différents selon la caractéristique des activités économiques (i.e. enregistrées *versus* non enregistrées). La première question que nous nous posons donc est de savoir si ces recommandations peuvent être suivies sans difficulté ou encore s'il existe d'autres défaillances de marché (ou asymétries d'information) que l'existence de l'économie non enregistrée qui peuvent affecter l'efficacité des politiques environnementales. Une autre question à laquelle il faut ensuite tenter de répondre est la suivante : dans une situation où le régulateur (le ministère de l'environnement ou l'agence de protection de l'environnement) ne connaît pas le véritable niveau d'émission de chaque entreprise qu'il souhaite réguler, à quel point différents mécanismes de mise en application affectent incitations des firmes pour réduire leurs émissions polluantes et investir en technologies d'énergie propre ? D'autre part, dans notre contexte, il pourrait être envisageable que les autorités fiscales et environnementales réagissent ensemble pour diminuer non seulement la taille de l'économie non enregistrée mais également les émissions polluantes. D'où la dernière question fondamentale : dans quelles conditions une politique de régulation environnementale (en coordination avec une politique fiscale ou pas) peut modifier la répartition de la production entre l'économie enregistrée et non enregistrée ? La réponse précise et satisfaisante à ces questions exige une étude théorique que nous allons exposer en deux chapitres : le premier (le quatrième chapitre) s'intéresse à l'efficacité environnementale des mécanismes d'incitation mis en place sous forme d'une taxe sur les émissions polluantes ; le deuxième (le cinquième chapitre) a pour objectif d'analyser l'impact d'une régulation environnementale sur les activités économiques non enregistrées.

Il ne fait pas de doute qu'avec l'apparition du livre séminal de Pigou (1920), la question des externalités ou des effets externes a fait l'objet d'une très abondante littérature. De nombreuses études se sont consacrées à la correction des externalités (s'il s'agit, évidemment, des externalités négatives, par exemple, la pollution) et ont proposé différents modèles afin de traiter tous les aspects du problème. Dans ces modèles, on étudie principalement l'efficacité relative de différentes politiques de régulation par les prix (taxation des émissions polluantes, d'où on déduit la taxe pigouvienne dont le niveau est donné par le dommage marginal créé par l'activité d'une firme) aussi bien que par les quantités (instauration des quotas ou création des marchés de permis négociables qui s'inspire largement du théorème de Coase (1960)). Nous voudrions préciser tout de suite que les chapitres théoriques de cette thèse s'intéressent seulement au premier type de politique de régulation qui est l'instauration d'une taxe sur les émissions. De plus, nous poursuivons un objectif encore plus spécifique qui est de nous focaliser sur un jeu stratégique entre le régulateur et la firme régulée. Ainsi, tout d'abord, l'analyse du comportement stratégique des entreprises face à la régulation environnementale est présentée dans le quatrième chapitre où nous développons des modèles d'information asymétrique. Dans ces modèles microéconomiques, l'existence de cette asymétrie d'information crée des opportunités de comportement stratégique de la part des firmes. D'une part pour résoudre ce problème de sélection adverse, et d'autre part, comme le coût d'observation du dommage causé par chaque agent est très élevé (Becker, 1968), pour minimiser la perte sociale, le régulateur doit trouver d'autres mécanismes et politiques de mise en application (*enforcement policy*). Pour cela, il est nécessaire non seulement de demander à chaque firme de déclarer son niveau d'émission et ensuite de contrôler les firmes avec une certaine probabilité afin de vérifier si leurs émissions se conforment à leur déclaration, mais aussi de mettre en place un système de sanction au cas d'une non conformité. Il est évident que ce type de pratiques peut augmenter le degré de conformité aux réglementations environnementales.

Dans la littérature, de nombreux travaux ont déjà été menés sur les comportements stratégiques des firmes en situation de régulation environnementale. Nous pouvons en citer quelques-uns : si on essaye de donner une interprétation de la "théorie de crime rationnel" (*theory of rational crime*) de Becker (1968), on peut dire qu'une firme se conformera au règlement environnemental si et seulement si la pénalité prévue de la violation dépasse le coût de conformité. Néanmoins, Harrington (1988) a montré que malgré le fait que la fréquence de la surveillance est faible et que les amendes sont rarement appliquées, les firmes américaines se conforment toujours aux règles fixées par les autorités environnementales à un degré beaucoup plus élevé que prévu par Becker (1968). Ce "paradoxe de Harrington" (Heyes et Rickman, 1999) est certes dû à la spécification de son modèle (existence d'un système de contrôle basé sur le degré de conformité des firmes mesuré lors des contrôles antérieurs), mais il peut nous conduire à penser qu'une firme peut se conformer aux normes environnementaux même lorsque son coût de conformité dépasse la pénalité prévue (Friesen, 2003). De par son cadre d'analyse, dans la littérature l'article le plus proche de notre analyse est celui de Macho-Stadler et Pérez-Castrillo (2006) qui, en utilisant une probabilité exogène de détection, montrent qu'une politique optimale de régulation environnementale doit se concentrer sur le contrôle (*auditing*) des firmes dont les émissions peuvent être suivies plus facilement (*easiest-to-monitor firms*). Par contre, nous montrons que l'endogénéisation de la probabilité de détection dans différentes configurations de contrôle des émissions peut fournir des résultats encore plus intéressants en ce qui concerne le niveau optimal des émissions polluantes et les efforts de R&D.

Comme nous le faisons dans le troisième chapitre, nous intégrons dans notre cadre d'analyse, sur un plan théorique cette fois, la question des activités économiques non enregistrées dans le cinquième et le dernier chapitre de cette présente recherche. Dans deux formes de concurrence duopolistique, à la Cournot et à la Stackelberg, nous étudions la décision de production des deux firmes, toujours en situation d'asymétrie d'information sur leurs émissions, l'une exerçant une activité économique dans l'économie enregistrée et l'autre dans l'économie non enregistrée. Deux types de politiques de régulation sont envisagés et discutés successivement : (1) la politique environnementale menée indépendamment de la politique fiscale avec une probabilité de détection qui est supposée exogène ; (2) la mise en place d'une coordination entre les autorités environnementales et fiscales qui utilisent la même probabilité de détection qui, cette fois-ci, est une fonction croissante de la taille de l'économie officielle. Afin de déterminer la forme de cette fonction, nous effectuons des tests économétriques décrits ci-dessus pour le cas de la Turquie. Ensuite, nous analysons en détail les effets de chacune de ces politiques sur le niveau de production des deux firmes.

Cette thèse de doctorat présente donc un ensemble de réflexions et de propositions théoriques aussi bien qu'empiriques orientées vers deux pôles complémentaires : le premier questionne la relation de long terme et de causalité entre l'activité économique (officielle et non enregistrée) et la consommation énergétique qu'elle *engendre* ; le deuxième examine l'efficacité environnementale et économique de différents mécanismes de régulation environnementale en présence de l'asymétrie d'information et les activités économiques non enregistrées afin de déterminer une politique environnementale optimale. La complémentarité des travaux présentés dans cette recherche vient du fait que si nous pouvons faire, à la lumière des résultats empiriques de cette thèse, des recommandations en matière de politique énergétique et environnementale, il faut tout de même considérer l'interaction entre la stratégie des firmes et différents mécanismes de mise en application de ces politiques.

Ces recherches peuvent sans aucun doute présenter un intérêt politique, économique ou encore juridique pour les pays en voie de développement plus spécifiquement pour la Turquie, pays candidat à l'adhésion à l'Union européenne (UE), qui, selon nous, doit augmenter ses efforts afin d'aboutir en 2020 aux objectifs de l'UE connus sous le nom de 20-20-20 : 20 pour cent de réduction de la demande d'énergie primaire ; 20 pour cent de renouvelable dans la consommation finale d'énergie ; 20 pour cent moins de gaz à effet de serre.

*

*   *

Summary of the international comparison analysis

Mainly initiated by the industrial revolution, with the extensive use, initially abundant non-renewable resources have become more and more scarce. Furthermore, as the main pollutants released from the combustion of these non-renewable resources (fossil fuels), global greenhouse gases emissions increased sharply during the last century. In parallel with these developments, energy consumption-economic growth-environmental pollution nexus has been addressed by both theoretical and empirical studies in the literature. Theoretical papers focus on the sustainable growth paths in the presence of non-renewable pollutant resources while empirical studies investigate whether there exist a long-run relationship and causality between the relevant variables. On the other hand, the results given in theoretical papers depend on both the model specification and the assumptions made, while the product of empirical studies suffers from the high sensitivity to the methodology employed and the period considered. As a result inconsistent and sometimes conflicting results are found in both of these two types of studies in the literature.

The present study has not aimed to provide such an analysis on this line of research. Instead, it has mainly focused on both the convergence issue and the relative performance of each country in the context of energy productivity and environmental efficiency in the energy use. In other words, the main feature of our analysis consists in giving an international comparison in order to evaluate the Turkish economy's performance with respect to energy productivity and environmental efficiency. For this purpose, first of all, using both Gini coefficient and Theil index some distributional analysis are provided. The results clearly support the view that in the global economy, there is a convergence in both overall energy productivity (i.e. total primary energy supply (TPES) per gross domestic product (GDP)) and environmental efficiency (CO_2 emission per TPES), while the mean of these two variables remain stable during the 35-year period from 1971 to 2005. Secondly, we build up an "energy-growth-environment" index in order to analyze in detail energy productivity and environmental efficiency in 132 countries over the same period. The results indicate that energy productivity is higher and more stable compared to the environmental efficiency in the country. Energy productivity in Turkey is the 49th among the countries involved for the years 1990, 2000 and 2005. However, the outlook of Turkey's environmental efficiency is not cheering : CO_2 emission per TPES in Turkey is the 87th, 112th and 110th among other countries for the years 1990, 2000 and 2005, respectively. Finally, the scores for each index are summed with equal weight to give an overall score, the minimum being 0 (i.e. the country having the best performance) and the maximum being 1 (i.e. the country having the worst performance). As a result, in the general "energy-growth-environment" index, Turkey is found to be one of the countries in the medium-low energy-environment efficiency group. In this index, compared to the Turkey's position, some of the OECD countries like Greece, Poland and Czech Republic have slightly worse performance while some developing countries like Brazil and Malaysia have better performance. These findings have important implications for both energy policy and environmental management in Turkey. Energy conservation programme should be followed, and for this purpose, governments should undertake (or grant a subsidy for) investments on energy saving technical progress. On the other hand, as we pointed out that Turkey has a relatively worse performance in the environmental dimension of sustainability, with the aim of switching to less carbon-intensive energy use in Turkey, governments should also take regulatory measures and use economic instruments such as energy taxes and subsidies (renewable energy resources like wind, hydro and geothermal). Such developments may decrease energy intensity and CO_2 emissions in Turkey.

In our view, Turkish government's goal should be to achieve in 2020 European Union's 202020 target : 20 percent reduction in primary energy demand ; 20 percent renewable in final energy mix ; 20 percent less greenhouse gases.

Chapitre 1

Sectoral energy consumption by source and economic growth in Turkey

1 Introduction

The aim of this first chapter is to provide a detailed analysis of the energy consumption in Turkey during the last 40 years. It investigates the causal relationships between income and energy consumption in two ways : first, the relationship is studied at the aggregate level ; then, we focus on the industrial sector. Furthermore, a descriptive analysis is conducted in order to reveal the differences in the use of energy resources.

The main corpus of this chapter is taken from Jobert and Karanfil [Jobert, T., Karanfil, F. (2007). "Sectoral energy consumption by source and economic growth in Turkey", *Energy Policy*, 35 (11), 5447-5456.]. Furthermore, we propose some extensions necessary to address (1) the relationship between different energy sources and economic activities and (2) the existence of an environmental Kuznets curve (henceforth EKC) in Turkey.

The process of economic development in the developing countries has involved a strong growth of energy demand over the last 50 years. As in most of the industrial countries, these countries had to reduce energy requirements due to rising energy prices following the energy crises in the 1970s. According to Stern and Cleveland (2003), if the level of economic activity and energy use are tightly coupled, the economy is called energy dependent and any typical energy policy can affect economic growth.

Jones' (2002) study reveals four stylized facts for the US economy for a 48-year period (1950-1998) :

- Four percent annual increase in energy efficiency (GDP per unit of energy used).

– One percent increase in per capita energy use.

– About one percent decrease in the share of energy cost in GDP.

– Decline in energy prices per unit of labor cost.

In a more theoretical study, Smulders and de Nooij (2003) build a growth model where the direction of technical change is endogenous, and confirm these stylized facts for Japan, West Germany, France and UK.

The causal relationship between economic growth and energy consumption has been studied in a large number of empirical studies with conflicting results. Using the energy consumption and gross national product (GNP) of the US economy over the period from 1947 to 1974, Kraft and Kraft (1978) argue that the direction of causality is from GNP to energy consumption. Their results indicate that the low level of energy dependence of the US economy enables energy conservation policies which have no effect on income (Jumbe, 2004). This pioneering study intensified the interest in the analysis of the relationship between income and energy consumption. Akarca and Long (1980), by simply changing the time period used in Kraft and Kraft (1978), found no statistically significant causal relationship.

The neutrality hypothesis is also found by Yu and Hwang (1984), Yu and Choi (1985), Yu and Jin (1992) and Cheng (1995). However, empirical studies focusing on some developing countries give disparate estimations of the causal relationship ; e.g. for different time periods, in Indonesia the direction of Granger causality (Granger, 1988) is from income to energy (Masih and Masih, 1996), but Fatai et al. (2004) found a unidirectional causality running from energy consumption to income. For the same country, energy and income were found to be neutral with respect to each other at least in the short run (Asafu-Adjaye, 2000). The empirical evidence is mixed also for industrialized countries ; e.g. Erol and Yu (1987) found a significant causal relationship between income and energy consumption in the case of Japan for the period 1950-1982, supporting the view that Granger causality runs from energy consumption to income. However, this result does not hold in a more restricted period, 1950-1973. Recently, Lee (2006) pointed out that their results are spurious and that the direction of causality runs from income to energy consumption.

Inconsistent results concerning the direction of the relationship might be due to (1) methodological differences and (2) the time period chosen. In recent studies, the cointegration technique, used first by Engle and Granger (1987), is commonly utilized to test for long-run equilibrium relationships. Johansen (1991) and Johansen and Juselius (1990) use the maximum likelihood procedure to detect Granger causality ; if two or more variables are cointegrated and have common trends, there is at least one long-run relationship between these variables ; hence, the direction of Granger causality can be tested through the vector-error correction model (VECM). Using this methodology, Soytas and Sari (2003) found, in the long run, a unidirectional causality running from energy consumption to GDP per capita and, in the short run, a bidirectional relationship in Turkey. In a recent study, Lise and Van Montfort (2007), using annual data over the period 1970-2003, found that, in Turkey, energy consumption and GDP are cointegrated and that there is a unidirectional causality running from GDP to energy consumption. For the same country, Sari and Soytas (2004), utilizing a small sample of disaggregate energy consumption and GDP (31-year period from 1969 to 1999), pointed out that 21 percent of the forecast error variance of GDP is explained by total energy consumption. This result is obtained through the generalized forecast error variance decomposition developed by Koop et al. (1996) and Pesaran and Shin (1998). The main advantage of this method is that it provides robust results regardless of the order in which the variables are entered into the VAR.

Although all of these studies contribute to investigating the relationship between energy consumption and economic growth, they have not sufficiently shed light on the dynamics of this relationship. We feel that the evolution of energy consumption and economic growth can be more efficiently analyzed if different sectors and different energy sources are taken into consideration, together with economic indicators such as population growth, capital intensity and sectoral production. The complexity of relationships among these variables requires a re-examination of the long-term linkage between energy consumption and income in Turkey.

The chapter has four important findings. First, it supports the neutrality of energy in Turkey. Hence, energy conservation policies may not be a stimulus to economic growth. Second, as in Greece (Hondroyiannis et al., 2002), energy use in industrial production in Turkey increased considerably, despite the 1970s' oil price shocks. This is a result of increasing capital intensity at the same time in Turkish industry. Hence, this pattern of economic development does not seem to be supported by energy-saving technical progress. Third, in the long run, economic activities have an impact on the electricity and petroleum products consumptions. Forth, economic development and CO_2 emissions in Turkey exhibit an EKC (called an inverted-U curve or a bell-shaped curve).

The chapter is organized as follows. In Section 2, we describe economic developments and the pattern of development of total energy consumption in Turkey since 1960s. We find no evidence of long-run relationship, and energy and income appear to be neutral with respect to each other. We then analyze trends in consumption in a sectoral level by energy type. In Section 3, we examine the links between production and energy consumption in the industrial sector and give possible explanations for the econometric results that this research provides. In each section we analyze also the existence of this relationship for four main energy sources, namely, electricity, gas, coal and petroleum products. In Section 4, we discuss our methodology employed to validate the EKC hypothesis and present estimates of the relationship between income and CO_2 emissions. We present the conclusions of our study and discuss policy implications in Section 4.

2 Economic developments and energy consumption in Turkey

2.1 Macroeconomic background

During the last 40 years, a fragile economic system has been created by boom-bust cycles produced by multiple growth and recession periods in the Turkish economy. For a better explanation of these cycles, the period (from 1960 to 2006) should be analyzed in three sub-periods. In the first 20 years (1960-1980) a closed and planned economy, in the following 20 years (1980-2000) an open economy with an export-led growth strategy and finally (2000 to present) the acceleration of structural reforms to obtain a sustainable growth.

According to the estimations of the Turkish Statistical Institute (TSI), between 1960 and 1980 the country's population has been growing at an average annual rate of 2.5 percent. The annual growth rate of population decreased to 2.2 percent in the next 20 years. Since 2000, excessive growth of population has relatively slowed down to an annual rate of about 1.6 percent. Turkey's population at the end of 2003 exceeded 70 million. This figure represents a 155 percent increase over the 27.7

million enumerated in 1960. In spite of this high population growth rate, GNP per capita more than doubled in this period.

Tab. 1.1 – Average annual growth rate of economic indicators and energy use in Turkey (%)

	1960-1979	1980-1999	2000-2003
GNP at fixed (1987) prices	5.12	3.98	2.65
GNP per capita	2.66	1.85	0.79
Energy consumption	5.27	3.76	3.71
Energy use per capita	2.8	1.64	1.83
Energy intensity (energy use/GNP)	0.14	-0.14	0.96

Data sources : Energy Balances of OECD countries and Central Bank of the Republic of Turkey

The main economic indicators and energy use summarized in Table 1.1 show that one of the most important characteristics of the Turkish economy is that, given that Turkey's population has grown quickly, GNP per capita and energy use per capita both increased about 2 percent per annum. In 1960 Turkey's real (at fixed 1987 prices) per capita income was 7.3 thousand YTL and in 2003 it was more than 17.7. The real per capita income in 2003 was 2.5 times that of 1960. The Turkish economy has experienced a *planned economy* during the 1960-1980 period. The main objective of this planning was to increase the capital stock. High level of subsidies and increasing real wages in the industrial sector created incentives for the substitution of capital to labor. In Section 2.3, we provide a detailed description of the evolution of production and energy consumption in the industrial sector. The aim here is to point out that this period can be called as a capital accumulation period in the Turkish industry. On the other hand, supported by restrictions on imports, a monetary policy that aims at decreasing real interest rates and keeping the Turkish lira overvalued was the main tool of adopting a strategy of import substitution industrialization (ISI). As the economy expanded, there was a very large growth in energy demand, especially those produced from fossil fuels. As in other developing countries, the ISI model of development in Turkey failed due to successive energy crises in 1973 and 1979. The two oil price shocks had persistent effects on the Turkish economy : cumulated external debt and, via the well-known pass-through mechanism, about a 100 percent annual inflation rate in the early 1980s.[1]

Reducing external debt and inflation on the one hand, and following the new trend of liberalization in the world economy on the other, imposed a number of structural changes on the Turkish economy. Hence, with support from the International Monetary Fund (IMF), a new reform programme was implemented by the Turkish government on February 14, 1980, with the adoption of the export-led growth strategy instead of the ISI. Under this programme, which can be called the neo-liberal experiment of Turkey, the government's role in the economy was changed. The main objective of the economic policy was to encourage exports and foreign direct investments with a new monetary policy that aimed at adapting exchange rates to match this strategy of market opening (IEA, 2001). On the other hand, subsidies and price controls were cut back ; low productivity in the state economic enterprises (SEEs) required the government to launch a privatization programme in 1985, followed by the full capital account convertibility,[2] which lifted foreign exchange controls, and

[1] The pass-through mechanism can be defined as change in local currency import prices as well as in domestic prices resulting from a change in the exchange rate. See Kara et al. (2005) for a detailed analysis of the impact of exchange rates on domestic prices in Turkey.

[2] The notion of capital account convertibility refers to the freedom to convert foreign financial as-

trade liberalization in 1989.

During the 20-year period of protectionism, from 1960 to 1980, production efficiency did not increase much, and it was not evident that the national industry could face the international competition in an open economy environment. However, as pointed out by Ertugrul and Selcuk (2001), the new strategy of stabilization and development that aimed at opening the Turkish economy to international markets was quite successful in restoring economic growth. The economy did not experience any recession between 1981 and 1988, and the average growth rate *per annum* of real gross domestic product (GDP) reached 5.8 percent. The high performance of the Turkish economy in the early 1980s, in spite of the military *coup d'Etat* on September 12, 1980, can be partially explained by the receipt of structural adjustment loans (SALs) from the World Bank.

In this period, increasing energy requirements were satisfied via world energy markets. In 1984, the government implemented a law that liberalized the energy market in order to open the market to the private sector. Investments in the energy sector decreased about 65.2 percent in an 8- year period following 1987. In 1973, the share of Turkey's energy production in the total primary energy supply (TPES) was 64% (IEA, 2001). By 1987, the total energy import exceeded the national energy production (see Fig. 1.1) and the ratio of national production to TPES diminished to

sets into local financial assets and vice versa at an exchange rate determined in the market. In order to promote capital account liberalization among the Organisation for Economic Co-operation and Development (OECD) member countries, the OECD Code of liberalization of capital movements was established in 1961. However, Turkey adopted general derogation that gives a dispensation from all operations specified in the Code. This derogation was dropped in 1985 and the Turkish economy adopted full capital account convertibility in the end of the 1980s. Further information can be found in OECD (2006).

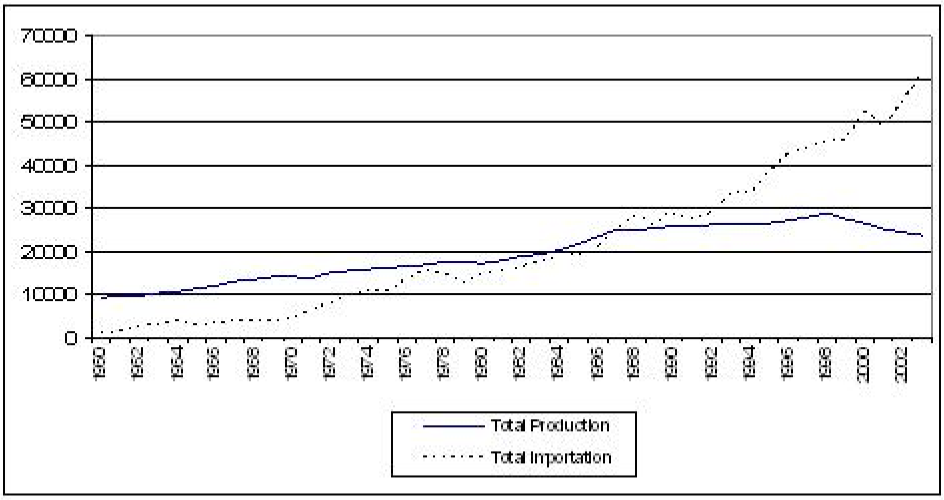

FIG. 1.1 – Energy production and import (kilo tonnes of oil equivalent). Data source : Energy Balances of OECD countries.

49% in 1990. This makes Turkey an energy import-dependent country, which is, due to increasing energy prices, the main factor of the increase in the total import-GDP ratio.[3] An effective export-led growth policy impeded the possible deterioration of the trade balance. However, dependency of the economic growth on the short-term capital inflows created a fragile equilibrium that became evident with financial crisis in 1994 and with Russian crisis in 1998.[4]

[3]Decreasing trend of energy prices stopped by the Gulf War ; the price of barrel of a crude oil rose above 27 dollar and average oil prices gained more than 72 percent over the period from November 1988 to the end of 1990.

[4]During the period July-September 1998, the Turkish economy was exposed to a net outflow of capital amounting to US $10.5 billion. Furthermore, devaluations of currencies of Asian countries and Russia decreased goods prices in international markets, thus Turkish export goods lost competitiveness against these countries. On the other hand, the volume of shuttle trade "exports" from Turkey to Russia dropped to US $2.2 billion after 1998, which was estimated to be close to US $9 billion in the mid-1990s. A more detailed analysis on the effects of Russian crisis on the Turkish

The crises of November 2000 and February 2001 were two of the biggest that Turkey has experienced in the history of the Republic. After two decades of neo-liberal reforms, it became clear that governments should take necessary measures to produce domestic macroeconomic stability, a factor that is undoubtly the *sine qua non condition* for an efficient financial globalization. Supported by IMF, the government launched a new restructuring and reform programme. The aim of the programme was to establish confidence, reduce inflation and increase economic efficiency.

Just as the government tried to increase the productivity of other production factors, it has also made considerable efforts to address the "3 Es", namely energy security, energy efficiency and environmental protection, in a sustainable manner (IEA, 2005). Intensifying R&D on energy technologies, in order to satisfy increasing energy demand with economic growth, and maintaining the security of energy supply (exploration activities, particularly in the south-eastern part of the country, and reduction of import dependence) constituted the main objectives of the energy policy objectives of the Eighth Five-Year Development Plan for the 2001-2005 period. Today, three main boards are responsible for the implementation of energy policies and the regulation of the energy market : The Ministry of Energy and Natural Resources (MENR), The General Directorate of Energy Affairs (EIGM) and The Energy Market Regulatory Authority (EMRA).

2.2 Methodology, data and empirical study

To measure the causal relationship between energy consumption and income, we use the notion of Granger causality and the notion of instantaneous (or contemporaneous) causality. These notions can be used when we are dealing with stationary

economy can be found in Uzumcuoglu and Kokden (1998) and Yukseker (2007).

series.

Traditionally, to test the causal relationship between two variables, the standard Granger (1969) test has been employed in the relevant literature. This test states that, if the past values of a variable X_2 significantly contribute to forecast the values of another variable X_1, then X_2 is said to Granger cause X_1 and vice versa.

Technically, this notion can be defined as follows : the process X_2 does not Granger cause the process X_1 if

$$E(X_{1t}/I_{t-1}(X_1), I_{t-1}(X_2)) = E(X_{1t}/I_{t-1}(X_1))$$

where $I_{t-1}(X_i)$ is the space generated by the linear combinations of the past values of X_i.

The definition of Granger causality does not mention anything about possible instantaneous correlation between X_2 and X_1. This second notion, instantaneous causality, can be presented as follows : the process X_2 does not cause instantaneously the process X_1 if

$$E(X_{1t}/I_{t-1}(X_1), I_t(X_2)) = E(X_{1t}/I_{t-1}(X_1))$$

where $I_t(X_i)$ is the space generated by the linear combinations of the present and past values of X_i.

With stationary series, the tests are based on the following regression as it was shown in Granger (1969) :

$$\begin{aligned} X_{1t} &= \delta_1 + \sum_{i=1}^{p} a_i X_{1t-i} + \sum_{i=1}^{p} b_i X_{2t-i} + u_{1t} \qquad (1.1) \\ X_{2t} &= \delta_2 + \sum_{i=1}^{p} c_i X_{1t-i} + \sum_{i=1}^{p} d_i X_{2t-i} + u_{2t} \end{aligned}$$

where δ_1 and δ_2 are constant terms, u_{1t} and u_{2t} are white-noise series and p represents the lag order. To test for the lack of Granger causality of the X_2 variable on the X_1

variable, a Fisher test is sufficient to see whether all the coefficients b_i are equal to zero. That is to say

$$H_0 : b_i = 0 \quad \forall i = 1, .., p$$

$$H_1 : \exists b_i \neq 0 \quad \forall i = 1, .., p$$

Similarly, the simple causal model given in (1.1) implies that X_1 is causing X_2 if some c_j is not zero. On the other hand, the test for instantaneous causality is based on the existence of correlation between the innovations : If u_{1t} and u_{2t} are correlated, then there is instantaneous causality. The more general model with instantaneous causality is

$$\begin{aligned} X_{1t} + b_0 X_{2t} &= \delta_1 + \sum_{i=1}^{p} a_i X_{1t-i} + \sum_{i=1}^{p} b_i X_{2t-i} + u_{1t} \qquad (1.2) \\ X_{2t} + c_0 X_{1t} &= \delta_2 + \sum_{i=1}^{p} c_i X_{1t-i} + \sum_{i=1}^{p} d_i X_{2t-i} + u_{2t} \end{aligned}$$

If $b_0 \neq 0$ and $c_0 \neq 0$, then instantaneous causality occurs and an information of X_{2t} can be used to improve the estimation of the first equation for X_{1t} and vice versa.

Developments in the time-series analysis have improved the standard Granger test. The first step is to check for the stationarity of the variables and then test cointegration between them. According to Granger (1988), the test remains valid with non-stationary and not cointegrated variables if the variables are differentiated ΔX_t. Furthermore, Toda and Phillips (1994) and Toda and Yamamoto (1995) propose a procedure to perform Granger causality test with non-stationary and cointegrated variables.

The first step is to verify the order of integration of the variable. We use unit root tests of Dickey-Fuller and Phillips-Perron. The second step involves testing cointegration using the Johansen (1991) and Johansen and Juselius (1990) approach.[5]

[5]Additional information about vector autoregressions and cointegrated processes can be found

Our empirical study has been carried out using annual time series for the period 1960-2003. The data for real GNP and industrial value added (IVA) are obtained from the Central Bank of the Republic of Turkey. Other variables, total, residential and industrial energy consumption are considered in different categories that consist of petroleum products, electricity, natural gas and coal consumption. The energy consumption variables are measured in thousand tons of oil equivalents (ktoe) and are taken from the *Energy Balances of OECD Countries* published by the International Energy Agency. Also the data for CO_2 emissions which are used in the analysis of EKC are from the *CO_2 Emissions from Fuel Combustion* published by International Energy Agency (IEA, 2005a). All variables are in logarithms.

First, we test the stationarity of the following series : energy consumption, energy consumption per capita, income and income per capita. Dickey-Fuller and Phillips-Perron unit root tests show that the logarithms of the series are not stationary, but that the series taken in first difference (growth rate) are stationary.[6]

Since the series are integrated of order one, we have searched for a cointegrating relation between GNP and energy consumption, both expressed in logarithms. To analyse the multivariate process generated by GNP and energy consumption, we have chosen to use the method proposed by Johansen (1991).[7]

According to Table 1.2, both the Trace and the Lambda max tests imply the absence of cointegration between energy consumption and GNP, which means that

in Hamilton (1994, chapters 11 and 19).

[6]Results are given in Appendix A.

[7]The advantages of this method compared with Engle and Granger's (1987) method are that it allows us to test for the number of cointegrating relations, does not impose an arbitrary normalization on the cointegrating vector and permits us to test for constraints on the coefficients of the cointegrating relation.

TAB. 1.2 – Johansen test for the number of cointegration relationships

	Eigenvalue	$H_0 : r$	Trace	L Max	Critical values at 95%	
					Trace	L Max
Model with GNP and energy	0,1076	0	8,75	4,67	15.41	14.07
	0.0947	1	3.56	3.56	3.76	3.76
Model with GNP and energy per capita	0,1078	0	8.26	4.79	15.41	14.07
	0.0791	1	3.46	3.46	3.76	3.76

r indicates the number of cointegrating relationships. The critical values for maximum eigenvalue and trace test statistics are given by Johansen and Juselius (1990).

these two variables do not have any long-run equilibrium. This is a sufficient condition to have an unsteady production function. Thus, these two series admit a VAR[8] representation with two non-stationary and non-cointegrated variables.[9]

Table 1.3 gives the P values for the non-causality tests as well as the signs of the estimated coefficients.

The results reveal that there is no causal relationship between total energy consumption and GNP in Turkey. In other words, the past values of energy consumption do not have an impact on GNP, and also the past values of GNP do not influence energy consumption in Turkey. On the other hand, the instantaneous causality test indicates that there is a very robust positive linkage between energy consumption and GNP.

[8] Akaike's information criterion (AIC) and Schwatz Bayesian criterion determine a VAR model of order 1.

[9] We do not discuss the methodology here to conserve space. Detailed explanations can be found in Hamilton (1994), Chapter 15.

TAB. 1.3 – P values of the Granger non-causality tests

		Causality	GNP	Energy
Model with GNP and energy	GNP equation	Granger	0.3(+)	0.52 (+)
		Instantaneous	-	0.00 (+)
	Energy equation	Granger	0.71 (-)	0.84 (-)
		Instantanteous	0.00 (+)	-
Model with GNP and energy per capita	GNP equation	Granger	0.27 (-)	0.53 (+)
		Instantaneous	-	0.00 (+)
	Energy equation	Granger	0.69 (-)	0.82 (-)
		Instantanteous	0.00 (+)	-

(-) Indicates that the sum of the coefficients is negative.

(+) Indicates that the sum of the coefficients is positive.

2.3 Energy consumption by sector

In analyzing energy use in Turkey, it is important to appreciate sectoral differences. As can be seen in Fig. 1.2, in 1960, the domestic sector contributed about 72 percent of the final energy consumption. The residential energy consumption increased annually by 2 percent between 1960 and 2003, while energy consumption in the industry and transport sectors increased by 7 percent and 5 percent, respectively. Hence, in the total energy consumption in 2003, industry became the largest sector, followed by the residential sector. In this period, energy consumption in services and agriculture has been increasing at an average annual rate of 14 percent and 8 percent, respectively. However, as these sectors are not intensive in energy use, the share of these sectors in the total energy consumption remained stable. Within the total energy consumption, the decreasing trend of the residential sector and the increasing trend of the industrial sector are in opposition of the trends observed in most of the industrialized countries. In France and Germany, for example, with the rise in income, residential energy consumption increased and exceeded industrial consumption. This is in part due to the large structural change of these economies from industry oriented production to a service-dominated system that decreased the share of industrial sector in the total energy consumption.

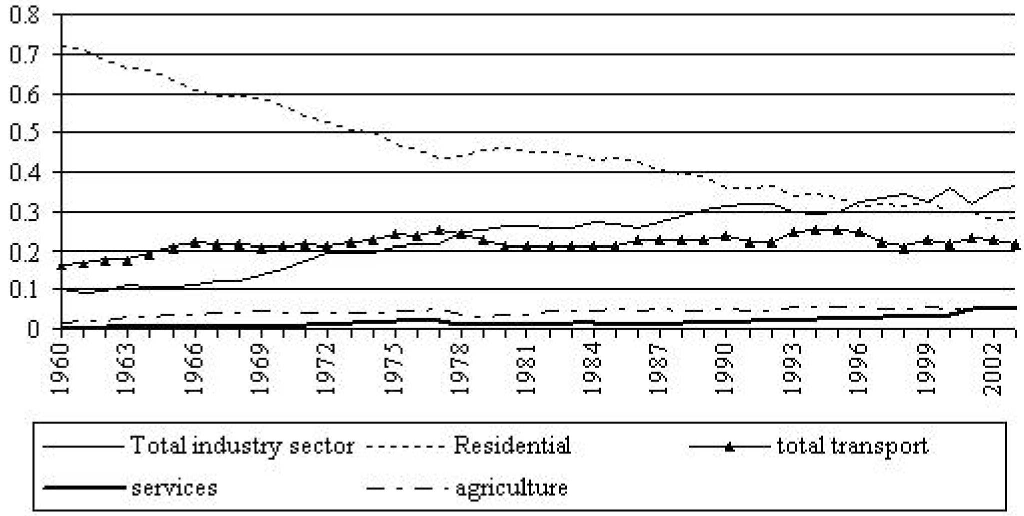

Fig. 1.2 – Energy consumption by sector. Data sources : see Fig. 1.1.

Given limited domestic energy sources and a high level of dependence on energy imports, the increasing trend in energy consumption in the Turkish industry has important economic consequences. Besides, this trend has adverse environmental impacts as it leads to a significant rise in CO_2 emissions. In 2002, the industry sector was the second largest contributor to CO_2 emissions, representing 26 percent of the total, following public electricity and heat production, which represented 28 percent (IEA, 2005). The remainder of our study will, thus, focus on the Turkish industry sector in order to analyse in detail the upward trend in energy use in this sector in an economic and environmental context.

Petroleum products consumed in the industrial sector increased relatively to electricity consumption. Coal is also used extensively in industrial production so that by 1980, at fixed 1987 prices, to create 1000YTL of IVA, primary energy requirements of the sector reached, approximately, 0.33 ktoe of oil, 0.19 ktoe of coal and 0.9 ktoe of natural gas. The evolution of primary energy consumption in relation to the IVA is given in Fig. 1.3.

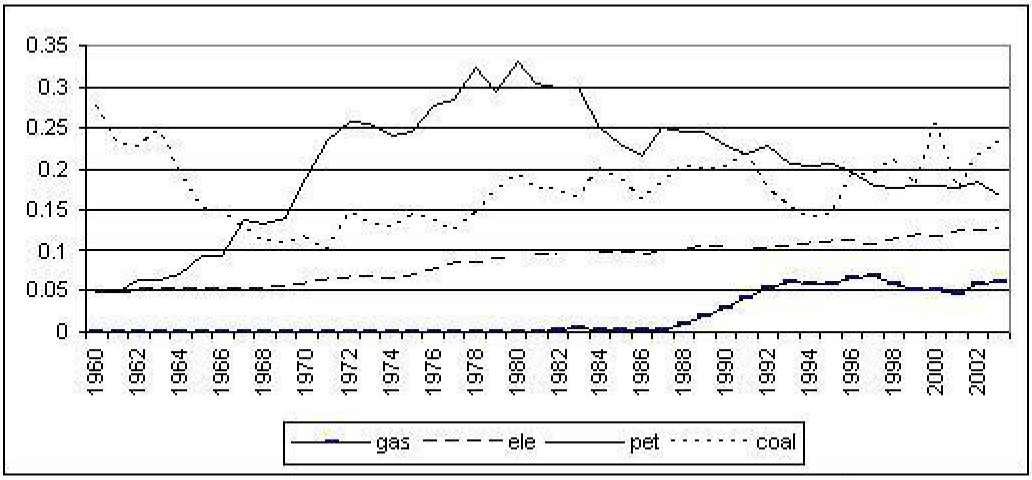

FIG. 1.3 – Energy consumption by source/industrial value added (ktoe per YTL thousand at fixed (1987) prices). Data sources : Energy Balances of OECD countries and Central Bank of the Republic of Turkey.

During the last 40 years, the industrial energy consumption by source is mainly characterized by being more balanced : in 1960, the energy consumption in the sector was *coal biased* ; the share of coal in the total industrial energy consumption was 73 percent. In 2003, it decreased to 39 percent but coal is still a commonly used energy source in the industry. As coal is one of the most polluting resources, the *coal-biased* energy consumption has negative environmental externalities in the economy. On the other hand, the shares of petroleum products and electricity are, in 2003, 28 percent and 21 percent, respectively. The use of natural gas in the industrial sector is still modest, about 10 percent of the total energy consumed in the industry.

TAB. 1.4 – Energy-related CO_2 emissions per GDP

$\frac{CO_2}{GDP}$ (kg CO_2 per 2000 US$)					
	1990	1995	2000	2003	% change (1990-2003)
France	0.33	0.31	0.29	0.29	-12.2
Germany	0.63	0.51	0.45	0.45	-27.5
Turkey	0.92	0.95	1.02	0.96	4.9

Data source : International Energy Agency (IEA).

In the industrialized countries, however, the pattern of industrial energy consumption by source is generally different. In France and Germany, in 2003, coal is the less-used energy source in the industrial sector, about 7 percent and 10 percent, respectively. Electricity and natural gas have increasing trends in both countries and energy consumption by source converges to a balanced growth path where the shares of natural gas, petroleum products and electricity are equal and stable, about 30 percent each. Hence, *neutral* energy use, which is not biased on a polluting resource, can lessen the environmental impacts of energy consumption in these countries (see Table 1.4).

Kaivo-oja and Luukkanen (2004) have used the decomposition method to compare energy-related CO_2 emission levels in the European Union member countries.

The aim of this method is to decompose the effects of both economic growth and technological change on sectoral energy consumption on the one hand, and the impact of change in the sectoral share of total production on energy consumption on the other. The results of the analysis clearly indicate that in France the energy intensity has not improved ; however, CO_2 intensity has decreased due to remarkable fuel switch to less carbon-intensive energy production. In Germany, after the oil crisis in 1973, not only CO_2 intensity but also energy intensity has decreased, mainly due to heavy investments in nuclear power.[10]

Section 3 extends the analysis to the Turkish industrial sector to illustrate the linkage between energy consumption and IVA. However before we proceed with this analysis, we would like to study the energy-income nexus using different energy sources.

2.4 Relationship between disaggregate energy consumption and GNP : an ARDL approach

In the previous subsection we have seen that the neutrality hypothesis between aggregate energy consumption and GNP can not be rejected. We believe that investigation of the possible long-run relationship between different disaggregate energy variables and GNP may provide some useful insights. For this purpose we use with GNP, gas, petroleum products, electricity and coal consumption. The methodology employed here consists of estimating autoregressive distributed lag (ARDL) models. As in the Johansen (1991) and Johansen and Juselius (1990) approach or in the

[10]It is not our intention in this chapter to make a detailed international comparison of energy consumption and CO_2 emissions, since the first half of the introductive chapter of this document is dedicated to such an issue.

residual based Engle and Granger (1987) two step procedure, the ARDL approach involves testing whether there exists a long-run relationship among the variables involved in a model. Nowadays, the ARDL framework has become popular among energy and environmental economists for conducting empirical research. The great advantage of ARDL modeling is that it can be applied when the variables are integrated of different orders. In other words, the Johansen (1991) and Johansen and Juselius (1990) cointegration test is not suited to the case where the variables involved are a mix of I(0) and I(1) and the ARDL approach represents a powerful alternative to this cointegration test. Thus, in the ARDL framework, it is sufficient to construct the following regressions and then use bounds testing procedure proposed by Pesaran et al. (2001).

$$\begin{aligned} \Delta GNP_t &= \beta_0 + \sum_{i=1}^{n} \beta_{1i} \Delta GNP_{t-i} + \sum_{i=0}^{n} \beta_{2i} \Delta EC_{t-i} + \beta_3 GNP_{t-1} + \beta_4 EC_{t-1} + \epsilon_{1t} \\ \Delta EC_t &= \alpha_0 + \sum_{i=0}^{n} \alpha_{1i} \Delta GNP_{t-i} + \sum_{i=1}^{n} \alpha_{2i} \Delta EC_{t-i} + \alpha_3 GNP_{t-1} + \alpha_4 EC_{t-1} + \epsilon_{2t} \end{aligned} \tag{1.3}$$

For each particular disaggregate energy variable (EC) we will test the null hypothesis of no cointegration by computing the F-statistics for $\beta_3 = \beta_4 = 0$ and $\alpha_3 = \alpha_4 = 0$. As discussed in Pesaran et al. (2001), the distribution of this F-statistic is non-standard irrespective of whether the regressors (gas, electricity, petroleum products, coal and GNP) are I(0) or I(1). Their study provide also upper and lower bounds for testing cointegration. If one finds an F-statistic greater than the upper bound, one rejects the null hypothesis of no cointegration. However if the F-statistic is found to be smaller that the lower bound, one should conclude that there is not any long-run relationship between the variables. The result from such an analysis will be inconclusive if the F-statistic is between the two bounds. Then we may switch to the Johansen (1991) and Johansen and Juselius (1990) approach to test for a cointegrating relationship among the variables.

Table 1.5 gives the F-statistics for the cointegration hypotheses. The results from the bound test indicate that cointegrating relationship exists only for electricity-GNP and petroleum products-GNP models. Furthermore, there exist long-run uni-directional causality running from GNP to petroleum products and bi-directional causality between GNP and electricity consumption. This is an interesting result, since although any causal relationship can be established between aggregate energy consumption and GNP (both from Johansen (1991) and Johansen and Juselius (1990) and ARDL approaches), at the disaggregate level some causal chains are detected. We may reasonably conclude that only electricity and petroleum products consumptions follow the changes in the GNP which is also found to be *electricity-dependent*.

3 Industrial sector

3.1 Developments in the industrial sector

As mentioned above, the period from 1960 to 1980 can be called as a capital accumulation period with adoption of a closed model of planned economy by the State Planning Organisation. The industrial sector was dominated by publicly owned SEEs, especially in some sub-sectors where capital requirements are too heavy and private investors hesitate to invest. During this period, the capital intensity of the production process increased sharply : the annual average growth rate of real capital stock was 5.9 percent in the 1960s and 8 percent in the 1970s.[11]

[11] This period can be analysed better by considering two sub-periods : economic crisis period (1978-1979) and pre-crisis period (1963-1977). In the first period, investment performance was

TAB. 1.5 – Bound test for cointegration analysis : GNP-disaggregate energy consumption nexus

Estimated equations		F-statistics
F(GNP|gas)		2.57
F(gas|GNP)		1.87
F(GNP|electricity)		6.3**
F(electricity|GNP)		10.2****
F(GNP|petroleum products)		1.96
F(petroleum products|GNP)		8.8****
F(GNP|coal)		4.39
F(coal|GNP)		3.63
F(GNP|total energy)		1.36
F(total energy|GNP)		4.22
Critical values[a]	Lower bound	Upper bound
10%	4.04	4.78
5%	4.94	5.73
2.5%	5.77	6.68
1%	6.84	7.84

The asterisks indicate the following statistical significance for the existence of a long-run relationship : ****1%, ***2.5%, **5%, *10%.

[a]Critical values for both lower and upper bounds are from Pesaran et al. (2001), p. 300, Case III : Unrestricted intercept and no trend.

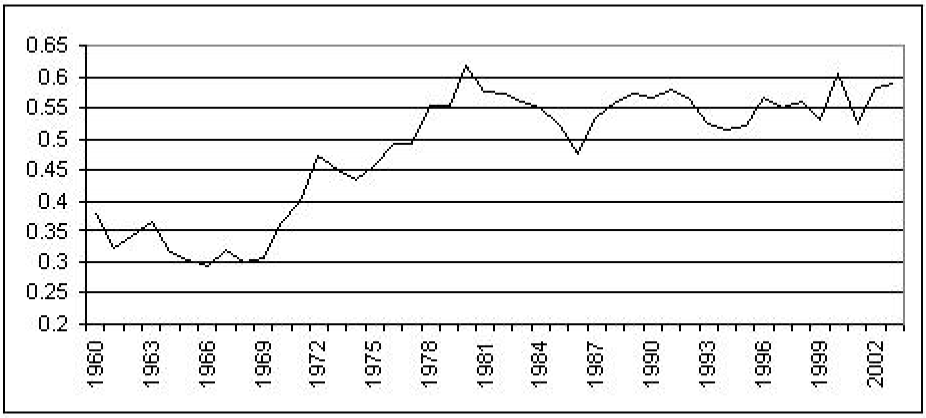

FIG. 1.4 – Energy consumption/industrial value added (IVA) (ktoe per YTL thousand at fixed (1987) prices). Data sources : see Fig. 1.3.

However, without any serious regulation to reduce the energy consumption and any energy-saving technical progress in the industry, this period of capital accumulation, dominated by a state-led inward-oriented growth strategy, raised the energy requirements of the Turkish industry. As a result, during this period, the increase in IVA exceeded the growth of energy consumption (see Figs. 1.4 and 1.5). Although, after the first energy crisis in 1973, energy consumption did not slow down, the second crisis in 1979 interrupted the pace of increase of energy consumption in the industrial sector.

During the1980s and 1990s, capital accumulation was mainly oriented towards tourism, education and medical sectors. The industrial sector's energy consumption was effectively reduced, thanks to the energy price shocks, the relative decrease of the capital stock in the industry and the adoption of an open economy strategy that facilitated the substitution of vintage capital by new information and communication

better, real private investment grew, on average, by 9.3% per year, and the annual growth rate of real public investment was more impressive, namely 12.2% (Ismihan et al. (2005)).

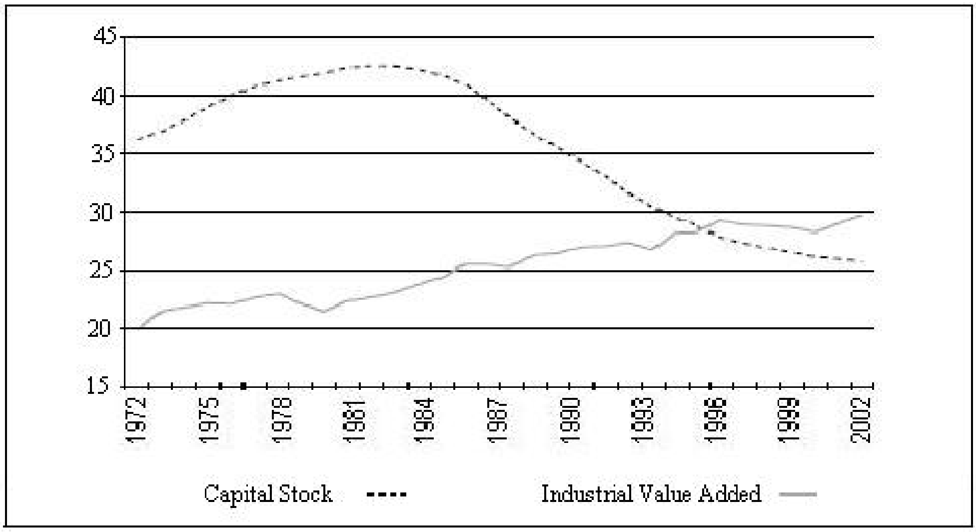

FIG. 1.5 – Share of industrial sector in total capital stock and in GNP (%). Data source : State Planning Organisation

technologies increasing the energy efficiency.

On the other hand, as we will discuss in Section 3.3, the electricity consumption/IVA ratio has an increasing trend ; in a very recent research, Soytas and Sari (2007) pointed out that there is a unidirectional causality running from electricity consumption to IVA.

3.2 Empirical study

We use the same methodology as in Section 2.2. The time series used here are IVA and energy consumption in this sector. Dickey-Fuller and Phillips-Perron unit root tests show that the logarithms of the series are not stationary, but that the series taken in first difference (growth rate) are stationary ; thus they are integrated of order one.

Table 1.6 reports the results of the test for the existence of cointegrating vectors and we find, once again, no evidence of a cointegrating vector between IVA and energy consumption in the industry, neither in the *level* model nor in the *per capita* model. This result is consistent with our previous remarks that the industrial energy consumption per unit of output in the sector is not stable during the 1960-2003 period.

TAB. 1.6 – Johansen test for the number of cointegration relationships

	Eigenvalue	$H_0 : r$	Trace	L Max	Critical values at 95%	
					Trace	L Max
Model with IVA and energy	0.2237	0	13.66	10.64	15.41	14.07
	0.095	1	3.03	3.03	3.76	3.76
Model with IVA and energy per capita	0.2084	0	13.61	9.82	15.41	14.07
	0.0863	1	3.49	3.49	3.76	3.76

r indicates the number of cointegrating relationships. The critical values for maximum eigenvalue and trace test statistics are given by Johansen and Juselius (1990).

As the series are non-stationary in levels and are not cointegrated, in order to test for causality we use a VAR model where the series are first differenced. The estimated coefficients of the Granger non-causality test are presented in Table 1.7.

In spite of the strong evidence of instantaneous causality between energy consumption and IVA, the results obtained by using two VAR models (*level* and *per capita*) seem to support the neutrality hypothesis among these variables.

As we have done in the previous section, in what follows, we will provide an disaggregate energy consumption analysis investigating the long-run relationship

Tab. 1.7 – P values of the Granger non-causality tests

		Causality	IVA	Energy
	IVA equation	Granger	0.42(+)	0.62 (-)
Model with IVA and energy		Instantaneous	-	0.00 (+)
	Energy equation	Granger	0.72 (+)	0.31 (-)
		Instantanteous	0.00 (+)	-
	IVA equation	Granger	0.48 (+)	0.59 (-)
Model with IVA and energy per capita		Instantaneous	-	0.00 (+)
	Energy equation	Granger	0.76 (+)	0.29 (-)
		Instantanteous	0.00 (+)	-

(-) Indicates that the sum of the coefficients is negative.

(+) Indicates that the sum of the coefficients is positive.

between different energy sources; namely, gas, electricity, petroleum products and coal, and industrial production.

3.3 Relationship between disaggregate energy consumption and industrial value added : an ARDL approach

Employing the ARDL framework given in Eq. (1.3) and using IVA and particular disaggregate energy sources consumed in the industry we try to identify the long-run relationships among these variables. The results are reported in Table 1.8. We find, once again, that there is a cointegrating relationship when the dependent variable is electricity consumption or petroleum products consumption. Technically, this re-

TAB. 1.8 – Bound test for cointegration analysis : IVA-disaggregate energy consumption nexus

Estimated equations		F-statistics
F(IVA|gas)		4.44
F(gas|IVA)		1.13
F(IVA|electricity)		2.27
F(electricity|IVA)		6.58**
F(IVA|petroleum products)		0.3
F(petroleum products|IVA)		12.39****
F(IVA|coal)		3.48
F(coal|IVA)		4.02
F(IVA|industrial energy)		1.67
F(industrial energy|IVA)		2.83
Critical values[a]	Lower bound	Upper bound
10%	4.04	4.78
5%	4.94	5.73
2.5%	5.77	6.68
1%	6.84	7.84

The asterisks indicate the following statistical significance for the existence of a long-run relationship : ****1%, ***2.5%, **5%, *10%.

[a]Critical values for both lower and upper bounds are from Pesaran et al. (2001), p. 300, Case III : Unrestricted intercept and no trend.

sult means that IVA is the first moving variable that is followed by electricity and petroleum products consumptions when all these variables are subject to a common stochastic shock. The implication of this finding is that a high level of industrial production leads to a high level of electricity and petroleum products demand. This result is in contradiction to those reported in two studies by Altinay and Karagol (2005) and Soytas and Sari (2007). While the former finds, using VAR models in levels, a unidirectional causality running from electricity consumption to income, the latter, utilizing VEC modeling technique, yields the result that uni-directional causality runs from electricity consumption to industrial value added.

We should also indicate, *in fine*, that, in the long run, any relationship has been found for other energy sources (coal and gas) and total industrial energy consumption which is consistent with the cointegration and the causality test results reported in the previous subsection.

In the following section, we move from the energy-income nexus to the environment-income nexus in order to provide further information on the effects of economic growth on the environmental degradation in Turkey, proposing an analysis of the environmental Kuznets curve hypothesis for Turkey.

4 Economic growth and emissions : an assessment of the environmental Kuznets curve in Turkey

Since the pioneering study by Grossmann and Krueger (1993) the relationship between economic development and pollution (or pollutant emissions) has been the focus of many econometric studies. As a matter of fact, the idea of representation of economic development and income inequality by an inverted-U curve was first introduce by Simon Kuznets, for which he received the Nobel Prize in Economics in 1971. So far, many studies investigated this relationship for different variables of environmental degradation (see Stern (2004) for an excellent literature review). The intuition behind the EKC is that pollution levels are directly related to the stages of economic development. More specifically, in the early stages, both economic growth and pollution increase and once income per capita reaches a threshold level (or "turning point"), then economic growth leads to a decrease in pollution. One can formalize this intuition by the following equation :

$$\ln e_t = \delta + \mu_1 \ln y_t + \mu_2 (\ln y_t)^2 + \epsilon_t \tag{1.4}$$

where ln indicates natural logarithms, e_t is an indicator of environmental degradation (in our case CO_2 emissions per capita), y denotes income per capita (in our case GNP per capita) and ϵ_t and δ are the the stochastic error term and the constant, respectively. The parameters μ_1 and μ_2 determine the shape of the curve : the relationship between CO_2 emissions per capita and GNP per capita has an inverted U-shape when $\mu_1 > 0$ and $\mu_2 < 0$. The "turning point" with respect to income, where emissions are at a maximum, is given by $\ln y_t = -\mu_1/2\mu_2$, hence $y_t = \exp(-\mu_1/2\mu_2)$. The model given by Eq. (1.4) can be estimated whether using panel data (multi-country studies) or time series data (country-specific studies). We present here the results for the case of Turkey. To date, to our knowledge there is no previous research focusing solely on the case of Turkey and investigating properly existence of an EKC by using CO_2 data. Nevertheless, there are some studies providing simplistic and incomplete analysis. For example, Lise and Van Montfort (2007), after investigating causal relationship between energy consumption and economic growth, claim that EKC hypothesis is not likely to be valid in Turkey. However, their estimation is based on a model describing a linear relationship between energy consumption (dependent variable) and economic growth (independent variable) (both in per capita terms), and they point out that regression results contradict the EKC hypothesis since the regression coefficient of economic growth has a significantly positive sign which should be, for the validity of the EKC hypothesis, smaller than 0.

On the other hand, when dealing with country-specific case studies time series properties of the data used should be checked carefully. In early and even in some recent studies this important point is neglected. For example, in a paper on the relationship between economic development and greenhouse gas emissions in economies in transition, Huang et al. (2008) fail to account for the stationarity of the series used in the study, in consequence their OLS results may be spurious.

Therefore after we transformed all variables into natural logarithms, we first check the stationarity of the variables involved in our analysis. The results are given in Table 1.10 in Appendix A.

Since all variables are integrated of the same order, we can test for a cointegration between them using Johansen (1991) and Johansen and Juselius (1990) approach. Table 1.9 shows the results of the cointegration test.

TAB. 1.9 – Johansen Test for the number of cointegrating relationships

Eigenvalue	$H_0 : r$	Trace	L Max	Critical values at 95%	
				Trace	L Max
0.540765	0	54.21483	32.68412	34.91	22.00
0.314757	1	21.53071	15.87525	19.96	15.67
0.125982	2	5.655457	5.655457	9.24	9.24

r indicates the number of cointegrating relationships. The critical values for maximum eigenvalue and trace test statistics are given by Johansen and Juselius (1990).

Both the trace and the maximum eigenvalue tests indicate 2 cointegrating relations with 95% confidence level. Furthermore, from this analysis we end up with the followig cointegrating equation :

$$\ln e_t = -121.3523 + 31.85553 \ln y_t - 2.071041 (\ln y_t)^2 + \epsilon_t \tag{1.5}$$

Following Engle and Granger (1987), we should examine whether the residual term from this cointegration equation is I(0). Test results reported in Table 1.10 in Appendix A indicate that ϵ_t is stationary, that is, I(0).

From Eq. (1.5) one may conclude that Turkey's CO_2 emissions conform very well with the EKC hypothesis. Moreover, EKC is computed and plotted from the estimated parameters ; $\delta = -121.3523$, $\mu_1 = 31.85553$, $\mu_2 = -2.071041$ (Fig. 1.6).

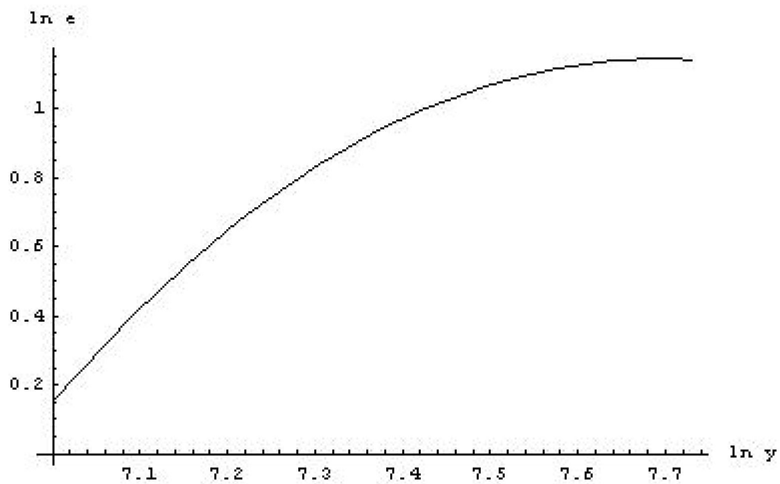

FIG. 1.6 – Application of the Environmental Kuznets Curve hypothesis for Turkey

On the other hand, the "turning point" income is estimated to be $\ln y_t = 7.6907$. Since in 2006 $\ln y_{2006} = 7.65$, we can reasonably expect that Turkey is about to pass beyond this point and that economic growth will lead to environmental improvement.

Finally we should mention that although the methodology employed in this section appears to be suitable to be adopted in such an analysis, several caveats need to be kept in mind. Lind and Mehlum (2007) describe the basic properties of an appropriate test for a U shaped relationship. The main idea is that an inverted U shaped curve requires that the slope of the curve be positive at the beginning and negative at the end of the data set. Satisfaction of this condition ensures that the extreme point is in the data range. In our case, this condition can be written as :

$$\mu_1 + 2\mu_2 \ln y_{Min} > 0 \tag{1.6}$$

$$\mu_1 + 2\mu_2 \ln y_{Max} < 0 \tag{1.7}$$

where $\ln y_{Min}$ and $\ln y_{Max}$ are, respectively, the minimum and maximum values of the variable $\ln y_t$. Lind and Mehlum (2007) argue that to test whether this condition is satisfied two ordinary t-tests should be carried out. Moreover, they propose a routine to perform the test in the software package Stata. Even though such a routine works well with cross-section and panel data, one should be careful when dealing with time series since t-statistics may be biased, so may be the estimated parameters. Hence, the estimated parameters from cointegration analysis given in Eq. (1.5) are used in order to see whether the conditions given in Eqs. (1.6) and (1.7) are fulfilled. Finally these calculations yield the result that at $\ln y_{Min}$ the slope of the curve is 4.54 while it is 0.72 at $\ln y_{Max}$, which means that the second condition given by Eq. (1.7) is slightly violated and that consequently the “turning point” income is not in the data range.

To end up this section we note that taking into account only the signs of the estimated parameters μ_1 and μ_2 validates the EKC hypothesis which becomes less evident once the slope of the curve at the upper and lower limits of the interval is accounted for. However, at least we are sure that the relationship between CO_2 emissions and GNP per capita in Turkey can be represented by an upward sloping concave curve : in the time period considered, the rate of increase in CO_2 emissions slows down with increasing values of income in Turkey.

5 Conclusions and policy implications

In this chapter, cointegration and Granger causality tests were applied in order to examine the long-run and causal relationship between real GNP and energy consumption in Turkey for the period 1960-2003. Our results show that there is no stationary linear cointegrating relationship between these two variables. Despite remarkable GNP per capita growth and stability in energy intensity, the neutrality hypothesis between real GNP and energy use in Turkey seems to hold.

A sectoral analysis was conducted by using cointegration and causality tests for the Turkish industry sector. The results imply that industrial energy consumption and industrial value added are neutral with respect to each other. We have chosen the industrial sector for at least two reasons : first, as we mentioned, the share of industry in total energy consumption increased at an average annual rate of 7 percent, and today industry is the biggest energy consumer sector in Turkey. The second reason, which is environmental rather than economic, is that fossil resources such as petroleum products and low-calorie domestic lignite are extensively used in the industrial sector. Therefore, the industrial sector is the second largest contributor to CO_2 emissions in Turkey.

We have also conducted the newly proposed ARDL bounds test (Pesaran et al., 2001) to examine the long-run relationship between different energy sources and both economic growth and industrial value added. The test have yielded a strong evidence for cointegration between energy consumption and economic activities when the dependent variable is electricity or petroleum products consumption and the independent variable is GNP or IVA. This implies that over the long run, economic activities are the key determinants of electricity and petroleum products consumptions.

Finally, using CO_2 emissions we have discussed the existence of an EKC in Turkey and, based on the results of econometric analysis, illustrated that Turkey partly exhibits (signs of the parameters) and partly does not exhibit (slope of the curve at the minimum and maximum values of $\ln y$) the EKC trend which makes the validity of the EKC hypothesis in Turkey open to question.

Our findings provide policy implications that may be used to determine future energy policy concerning economic growth and environmental protection. As the results confirm the neutrality hypothesis, in the case of Turkey, in the long run, an energy-saving programme can be followed both at the national and at the industrial level without harming economic growth. Furthermore, decreasing energy intensity will reduce dependence on energy imports. For the environmental question, significant efforts have to be made to intensify R&D on energy technologies in order to switch to less carbon-intensive energy use. The MENR, the EIGM and the EMRA should take the necessary measures to encourage the use of renewable energy resources. For this purpose, the law on utilization of renewable energy resources that encompasses wind, solar, geothermal, biomass, biogas, wave, current and tidal energy resources has been adopted on 18 May 2005. Besides, Turkey reopened its nuclear programme in order to have three nuclear power plants in operation by 2015. The share of nuclear energy in the total electricity consumption is planed to be a minimum of %8 in 2020 and %20 in 2030.

As the study results indicate that electricity and petroleum products consumptions follow economic activities, economic growth in the country increases mainly the demand for electricity and petroleum products. As a result, these nuclear power plants are regarded as the fastest way to satisfy the increasing electricity demand. Such developments are also expected to reduce CO_2 intensity in Turkey in the near future, which will be consistent with our EKC analysis results.

Before we close this chapter, we would like to lay emphasis on the fact that since unrecorded economic activities have an important weight in developing countries where the recorded (or official) GDP suffers from considerable measurement problems, investigation of the relationship between recorded GDP and energy consumption may lead to biased results. Acknowledging this important limitation on the quality of the data used for GDP, the results of this chapter should be interpreted with care. Thus, if it is not accurate to use these data in an analysis on the energy-income nexus, another solution may be to estimate the size of unrecorded economy and then to re-examine the long-run relationship between *true* GDP (that is the sum of *observed* GDP and unrecorded economy) and energy consumption. For this purpose the second chapter is dedicated to the estimation of the size of unrecorded economy in Turkey, offering some perspectives for readers unfamiliar with estimation methods used in the literature.

6 Appendix A. Stationarity tests

Tab. 1.10 – Results of unit root tests

Variable	Augmented Dickey-Fuller (ADF)		Phillips-Perron (PP)	
	Levels	First differences	Levels	First differences
GNP	-1.998	-7.730	-1.944	-7.270
Energy	-1.546	-7.204	-1.447	-7.212
GNP per capita	-2.411	-7.415	-2.410	-7.402
Energy per capita	-1.902	-7.283	-1.869	-7.317
CO_2 per capita	-1.240	-6.201	-1.166	-6.237
square of GNP per capita	-2.541	-7.526	-2.567	-7.520
Critical values				
1%	-4.214	-3.634	-4.214	-3.634
5%	-3.528	-2.952	-3.528	-2.952
10%	-3.197	-2.610	-3.197	-2.610
ϵ_t	-5.986		-5.131	
Critical values				
1%	-2.634		-2.631	
5%	-1.950		-1.950	
10%	-1.606		-1.607	

Chapitre 2

Estimation of real GDP and unrecorded economy in Turkey based on environmental data

1 Introduction

The purpose of this second chapter is to estimate the real gross domestic product (GDP) and unrecorded economy for Turkey using the Kalman filter technique. Using different tests, in the previous section we have investigated the causal relationship between energy consumption and GDP for Turkey. However, the results from an analysis taking into account the size of unrecorded economy may be more reliable than those of earlier investigations.

The estimation method employed in this chapter is original in that it uses economic variables (GDP, country population) as well as environmental variables (carbon dioxide (CO_2) emission, forest area) in order to estimate GDP, which is an unobserved variable in the model developed here. The remainder of the chapter follows directly from Karanfil and Ozkaya [Karanfil, F., Ozkaya, A. (2007). "Estimation of real GDP and unrecorded economy in Turkey based on environmental data", *Energy Policy*, 35 (10), 4902-4908.]. The analysis provided in this chapter is a prelude to the central purpose of the next chapter : in the energy consumption-income nexus how does unrecorded economy matter ?

Unregistered economic activities are one of the most important problems, especially in developing countries. Since the size of unrecorded economy is not known exactly, the determination and implementation of macroeconomic and social policies become very critical. Before we discuss the methods used for the estimation of the size of unrecorded economy, we should mention that there is not consensus on the definition of unrecorded economy.

According to the definition of Smith (1994), underground or shadow economy consists of "market-based production of goods and services, whether legal or illegal that escapes detection in the official estimates of GDP".[1] It means that the difference between real gross domestic product (GDP), that we call *true* GDP (or corrected measure of GDP), which is the unobserved state variable, and officially calculated GDP, that we call *observed* GDP, gives the size of unrecorded economy. Besides, in developing countries, illegal activities (like smuggling) as well as tax evasion in legal activities or other economic activities that are not criminal (like peddling) are the main sources of the unrecorded economy.

There are two types of data sources available for the estimation of the size of unrecorded economy.[2] Empirical studies that are based on micro data sources are often very costly and cause some methodological problems. These studies, called direct approaches, can provide detailed information about the unrecorded economy. However, this method of the sample survey will be biased if the respondents do not tell the truth and choose not to cooperate with the interviewer. The second approach widely used consists of measuring the size of unrecorded economy by using macroeconomic indicators such as GDP, employment or aggregate money demand. Therefore, this approach is called in the literature as the indirect or indicator approach. There are several methods in the indirect approach. First, the size of unrecorded economy is measured by using national account statistics. The gap between the expenditures and the income (or production) measurements of GNP gives the extent of the unrecorded economy. However, both the errors and the omissions in these two types of

[1] In the literature, there are several appellations for the underground economy, such as unregistered ; unrecorded ; informal ; subterranean ; hidden ; clandestine ; second ; parallel. For a detailed classification of the different types of "underground" economic activities, see Feige (1990).

[2] We just summarize here the methods used currently in the measuring of unrecorded economy. In order to conserve space, we do not analyze in detail the weaknesses or advantages of each method. For a detailed discussion about the subject, see Thomas (1999) and Frey and Pommerehne (1984).

GNP measurements cause biased estimations of unrecorded economy. Second, in an economy, if the growth rate of employment is smaller than that of labor supply, it can be seen as an indicator of increasing unrecorded economy. However, this method neglects different causes of variations in the rate of participation.[3]

Using the well-known Fisher's quantitative theory of money, Feige (1979) introduced a new method called the transaction approach. According to this method, the differences between total transactions and nominal GNP give the size of unrecorded economy. Using this method, Temel et al. (1994) estimated the unrecorded economy in Turkey to be 0-26 percent of the GNP for the period 1970-1992. On the other hand, Cagan (1958) developed a different method called the currency demand approach. This method was used for Turkey by Ogunc and Yilmaz (2000) to estimate the unrecorded economy as 11-22 percent of GNP for the period 1971-1999. Tanzi (1983) used the same method in an econometric approach. The main idea of the currency demand approach is that, as the tax pressure is the most important cause of the unrecorded economy, an increase in the tax burden will increase the size of unrecorded economy. On the other hand, since the transactions in the unrecorded economy are paid in cash if the unrecorded economy is extended, the currency demand will rise. The difference between transactions before and after tax rise will give the size of unrecorded economy. Tanzi's econometric approach is applied to the Turkish economy by Temel et al. (1994), which argues that the size of unrecorded economy varies between 6 and 20 percent of the GNP for the period

[3] This method is called the Italian approach, and the intuition behind this approach is that the official statistics of the labor force underestimate the labor supply. Contini (1981) argues that the true participation rate is 10-20 points higher than the official one, and that this difference accounts in particular for women, young and aged people who hold irregular jobs and do not reveal their true status to official investigators for fear of losing their "right to unlawful work".

1975-1992. On the other hand, Cetintas and Vergil (2003) gives another estimation of the size of unrecorded economy that is about 18-30 percent of the GNP for the period 1971-2000.

Both the Kaufman and Kaliberda (1996) electricity consumption method and the Lacko (1998) household electricity approach indicate that electricity consumption is a good indicator of the economic activity and that the gap between the growth rate of GDP and growth rate of electricity consumption gives the growth rate of the unrecorded economy. There exists no study applying these methods to the Turkish economy.

In this study, we do not focus on the causes of the unrecorded economy and its effects on the official economy. However, we should mention here that there are multiple causes and effects of the unrecorded economy and that each method described briefly above considers the unrecorded economy as though it has a unique cause and unique effect. The multiple indicator multiple causes (MIMIC) model, introduced by Frey and Weck (1983a, b), estimates the unrecorded economy, which is an unobserved state variable in the model, using two sets of structural equations : on the one hand the model gives the relationship between different causes of unrecorded economy and its size, on the other hand the model establishes the causal relationship between the size of unrecorded economy and the macroeconomic indicators. Savasan (2003), using the MIMIC model that covers the period 1970-1998, estimated the size of unrecorded economy as varying between 10 and 45 percent of the GNP in Turkey.

In this chapter as well as in later chapters of this thesis, we do not wish to enter into a long discussion of the origins and characteristics of the unrecorded economy in Turkey, partly because this is a complex phenomenon and it is difficult to accurately describe all causes of unrecorded economic activities, but it is also because

Tab. 2.1 – Comparison of total tax wedges in selected OECD countries (average rate in %)

Countries	2000	2001	2002	2003	2004	2005	2006	2007
Belgium	57.1	56.7	56.3	55.7	55.4	55.5	55.5	55.5
France	49.6	49.8	49.8	49.8	49.9	50.0	50.2	49.2
Ireland	28.9	25.8	24.5	24.2	24.0	23.5	23.0	22.3
Mexico	12.6	13.2	15.8	16.8	15.3	14.7	15.0	15.3
Norway	38.6	39.2	38.6	38.1	38.1	37.2	37.4	37.5
Turkey	40.4	43.6	42.5	42.2	42.8	42.8	42.7	42.7
United States	30.4	30.3	30.1	29.9	29.8	29.7	29.9	30.0
EU19	43.8	43.2	42.8	42.7	42.9	42.7	43.1	43.0
OECD - Total	37.8	37.5	37.5	37.3	37.5	37.3	37.7	37.7

Data source : OECD.

some politically tendentious views may be derived from such a discussion, which we want to avoid in this document. Nevertheless, we may mention that even the most cited causes are not so evident as they seem intuitively. For instance, Table 2.1 provides a brief comparison of the total tax wedges including employer payroll taxes in some OECD countries which represent employees' and employers' social security contributions and personal income tax less transfer payments as percentage of gross labor costs (gross wage earnings plus employers' social security contributions). Although in Turkey this ratio is slightly higher than the OECD average, it is very close to the EU19 average. We may reasonably doubt the claim that payroll taxes have an important impact on the extent of the informal sector. Furthermore, viewed from the demand side, value added tax (VAT) rates do not seem to be explanatory neither. For example in 2007, while the VAT in Turkey is 18 percent, in Belgium, France, Germany, Spain and Canada it is 21, 19.6, 19, 16, 7 percent, respectively. It is thus obvious that looking at purely economic indicators may not be sufficient to understand the reasons of the emergence of a large unrecorded economy in Turkey (see *infra* Table 5.1 in Chapter 5 for an international comparison of the size of the unrecorded economy).

The main contribution of the present chapter is that it employs a new methodology to estimate the unrecorded economy. We use the Kalman filter technique to measure the size of unrecorded economy in Turkey over the period 1973-2003. This technique is certainly not a new tool in economic literature. However, to the best of our knowledge, no study uses Kalman filter for estimating the real GDP in an environmental manner. This approach offers the opportunity to future researchers to investigate how large the unrecorded economy is for all developing countries.

The chapter is organized as follows. In the next section, after we briefly describe the sources of environmental and economic data used in our survey, we present the methodological approach. We discuss the results of our analysis in Section 3. Some concluding remarks are presented in the final section.

2 Methodology and empirical findings

The empirical study has been carried out using annual time series for the period 1973-2003. The data for *observed* GDP are obtained from the Central Bank of Turkish Republic and the country population is taken from the Prime Ministry State Institute of Statistics (SIS). The forest area is obtained from the Ministry of Forest of Turkey.

The data for CO_2 emissions, calculated using the intergovernmental panel on climate change (IPCC) method[4], are obtained from the *CO_2 Emissions from Fuel Combustion* published by International Energy Agency (IEA, 2005a). All variables are in natural logarithms.

In some recent studies time series properties are not perceived properly. For example, Say and Yucel (2006) examined the energy consumption and CO_2 emissions in Turkey and performed regression analysis in order to forecast the total energy consumption and CO_2 emissions up to 2015. Even though the study argues that total CO_2 emission values predicted by IPCC method are higher than those obtained by the relevant model, as the authors did not check the non-stationarity of the variables involved, their model is estimated incorrectly, and the results given are consequently biased.

We determined the time series properties of the variables used in this study by Augmented Dickey-Fuller (ADF) (Dickey and Fuller (1979)) and Phillips-Perron (PP) (Phillips and Perron (1988)) unit root tests. The null hypothesis of non-stationarity cannot be rejected by the unit root tests for the variable *observed* GDP (GDP_t^{obs}). We can hence find out that GDP_t^{obs} is integrated of order one, that is, I(1).[5] We are making the assumption that the *true* GDP (GDP_t^c), which is the

[4]In order to calculate CO_2 emissions, each fuel is converted to a common energy unit which is terajoules (TJ) or thousands of tonnes of oil equivalent (ktoe). The next step consists of multiplication of the consumption of each fuel by carbon emission factor which is different for each one. Than the carbon stored is calculated. We present in more detail the methodology used in the estimation of CO_2 emissions in Appendix A. For more information about the methodology, IPCC Guidelines are available from the IPCC Greenhouse Gas Inventories Programme (http ://www.ipcc-nggip.iges.or.jp)

[5]Results of ADF and PP unit root tests are given in Appendix B.

unobserved variable in the model, is also I(1). We then consider the following time series regression :

$$GDP_t^{obs} = \gamma + \delta t + \beta GDP_{t-1}^{obs} + \epsilon_t \tag{2.1}$$

where γ is a constant term and $\beta = 1$ provided by ADF and PP unit root tests' result. The variable t is introduced in order to capture time trend of GDP and GDP_{t-1}^{obs} is the lagged GDP term. ϵ_t represents shocks to the system which are assumed to be i.i.d. with zero mean and constant variance. Eq. (2.1) can be written as follows;

$$GDP_t^{obs} - GDP_{t-1}^{obs} = \Delta GDP_t^{obs} = \gamma + \delta t + \epsilon_t$$

where Δ represents the first difference operator.

Table 2.2 and 2.3 present the estimation results of linear regression of two alternative representations of Eq. (2.1). The time trend is not significant. The estimated GDP equation above will be introduced in the Kalman filter (Eq. (2.9)).[6]

TAB. 2.2 – Statistical results of the regression for the equation $\Delta GDP_t^{obs} = \gamma + \delta t + \epsilon_t$

Independent variables	Coefficients	Standard error	t-Statistics	Significance level (P)
γ	0.0487259	0.0154714	3.15	0.004
t	-0.0006201	0.0010399	-0.60	0.556

$$CO2_t = \alpha_1 FRST_t + \alpha_2 GDP_t^{obs} + \alpha_3 \Delta CP_t + \omega_t \tag{2.2}$$

Eq. (2.2) specifies the CO_2 emission ($CO2_t$) as the sum of forest area ($FRST_t$), real GDP (GDP_t^{obs}) and country population (CP_t). Note that ω_t should have the same

[6]It is important to make it clear that as we do not have any statistical information about the TGDP series, we make the assumption that they have the same time series properties as OGDP. That is why GDP^{obs} is replaced by GDP^c in Eq. (2.9).

TAB. 2.3 – Statistical results of the regression for the equation $\Delta GDP_t^{obs} = \gamma + \epsilon_t$

Independent variables	Coefficients	Standard error	t-Statistics	Significance level (P)
γ	0.038495	0.0082154	4.69	0.000

properties as ϵ_t, that is, i.i.d. In the next section, we analyze the properties of ω_t in order to perform the Kalman filtering.

Before we pass to the analysis on the time-series properties of the variables involved in Eq. (2.2), it might not be useless to discuss the specification of the relationship in Eq. (2.2). One may think that only energy consumption data can be used with GDP to estimate $TGDP$ instead of using other variables. However, we do not think that this is the appropriate procedure to perform the Kalman filtering in our case. The first reason for this is that it should be perceived that omitted variable bias may be raised in a bivariate framework. Entering other variables into the system may remove this bias from the analysis. The second reason, at least as important as the former one, is that in the Kalman filter framework, as it will be discussed in the next section, the more we have observed variables used in the estimation of un unobserved variable, the more our estimation is reliable. That is why indirect (or *exogenous*) variables such as country population and forest area are used to increase *the Kalman filter gain*. Furthermore, it should be indicated that, as the $TGDP$ series will be obtained using Eq. (2.2) with GDP equation, observed variables in Eq. (2.2) should be correct. In other words, weaknesses of these variables (errors or omissions) may lead to incorrect estimation of $TGDP$. This concern also leads us to another important questions : do CO_2 emissions calculated from fuel combustion reflect all economic activities in the country including both recorded and unrecorded activities ? The significance of this question comes from the fact that some unrecorded economic activities may use also *unrecorded energy* which is not taken into account in the estimation of CO_2 emissions. We leave this discussion to the next chapter, and just note here that unfortunately we do not have any information on the share of *unrecorded energy* in total energy consumption and that, as a result, we do not dispose *true CO_2 emissions*. That is why we do not know to what extend this could have influenced the results proposed in this chapter.

Generally, in the empirical literature, the explanatory variables stated in Eq. (2.2) are assumed to exhibit non-stationary behavior. Therefore, we will be first performing non-stationarity analysis to relevant variables. Using ADF and PP unit root tests, we found out that these variables are integrated of order one (I(1)), except the country population, which is found to be integrated of order two (I(2)). Thus, first we take the first difference of CP_t ($\Delta CP_t = (CP_t - CP_{t-1}) \sim I(1)$) and then we test whether there exists any cointegration relation among these I(1) variables or not, as shown by the following equation :

$$\beta_1 CO2_t + \beta_2 FRST_t + \beta_3 GDP_t^{obs} + \beta_4 \Delta CP_t \sim I(0) \tag{2.3}$$

More specifically, we search a cointegration vector that can be represented as follows :

$$b : \left[1; \frac{-\beta_2}{\beta_1}; \frac{-\beta_3}{\beta_1}; \frac{-\beta_4}{\beta_1}\right] \Leftrightarrow b : [1; \alpha_1; \alpha_2; \alpha_3] \tag{2.4}$$

The results of the cointegration test are presented in Table 2.4.

According to Table 2.4, trace test indicates 1 cointegrating relation with 95% confidence level. Moreover, the elements of the cointegration vector shown by (2.4), which are the unknown coefficients of Eq. (2.2) are all significant at 5% level. The growth of country population and real GDP increase CO_2 emissions. In addition, the forest area has the expected sign. The more the forest area, the more the absorbed CO_2 emissions.

TAB. 2.4 – Johansen Test for the number of cointegrating relationships

Eigenvalue	$H_0 : r$	Trace	L Max	Critical values at 95%	
				Trace	L Max
0.523799	0	42.82083	20.77362	40.17493	24.15921
0.327193	1	22.04721	11.09633	24.27596	17.79730
0.263074	2	10.95088	8.547506	12.32090	11.22480
0.082254	3	2.403375	2.403375	4.129906	4.129906
Unrestricted cointegrating		β_1	β_2	β_3	β_4
coefficients		-26.20394	-76.44599	30.04003	455.6536
Normalized cointegrating			α_1	α_2	α_3
coefficients		1	-2.917347	1.146394	17.38874

r indicates the number of cointegrating relationships. The critical values for maximum eigenvalue and trace test statistics are given by Johansen and Juselius (1990).

3 Kalman filtering

The idea of the Kalman filter is to represent a dynamic system in a particular form called the state-space modeling. The Kalman filter can be viewed as an algorithm for sequentially correcting a linear projection for the system. Thus, the Kalman filter and its extensions are generally used to estimate unobserved state values from observed (measured) variables.[7] The general form of the state-space formulation can be written as follows ;

$$x_t = F x_{t-1} + v_t \qquad \textit{(State equation)}, \tag{2.5}$$

$$y_t = A' x_t + H' z_t + e_t \quad \textit{(Observation equation)}, \tag{2.6}$$

[7] We do not discuss the methodology here to conserve space. Detailed explanations can be found in Brown and Hwang (1997) and in Hamilton (1994) ch.13.

where y_t denotes $(n \times 1)$ vector of variables observed at date t and x_t denotes the $(r \times 1)$ vector of unobserved variables at date t. Let F,A' and H' be matrices of parameters of dimension $(r \times r)$, $(n \times k)$ and $(n \times r)$.

The $(r \times 1)$ vector v_t and the $(n \times 1)$ vector e_t are white noise vectors (normally distributed i.i.d. errors) which are assumed to be uncorrelated and to have covariance matrices Q and R, respectively. Furthermore, z_t is the vector of exogenous variables. In this respect, using the cointegration test results reported in Table 2.4, our scaler observation equation is :

$$CO2_t = -2.917347FRST_t + 1.146394GDP_t^c + 17.38874\Delta CP_t + \omega_t \tag{2.7}$$

We statistically tested and found that the observation noise ($\omega_t \sim AR(1)$) is not a white noise. Regression results are shown in Table 2.5.

TAB. 2.5 – Statistical results of the regression for the equation $\omega_t = \varphi_1 + \varphi_2 t + \varphi_3 \omega_{t-1}$

Independent variables	Coefficients	Standard error	t-Statistics	Significance level (P)
ω_{t-1}	0.3075607	0.1821516	1.69	0.103*
t	0.0077864	0.0025668	3.03	0.005
φ_1	0.1149537	0.0233174	4.93	0.000

*Significant at 10% level.

The estimated equation for ω_t is thus

$$\omega_t = 0.1149 + 0.0077t + 0.3075\omega_{t-1} + u_t \tag{2.8}$$

where u_t is i.i.d ($u_t \sim N(0, R)$ with $R \in I$). As the Kalman filter Algorithm requires that the observation noise should be a white noise, we replace Eq. (2.8) with ω_t in Eq. (2.7).

According to Table 2.3 the state equation can be written as follows :

$$GDP_t^c = 0.0384 + GDP_{t-1}^c + \epsilon_t \tag{2.9}$$

Then, the Kalman filter procedure can be applied to estimate the new state vector x_t (GDP_t^c in our model).

The *observed* GDP and the Kalman filter response are plotted in Fig. 2.1.

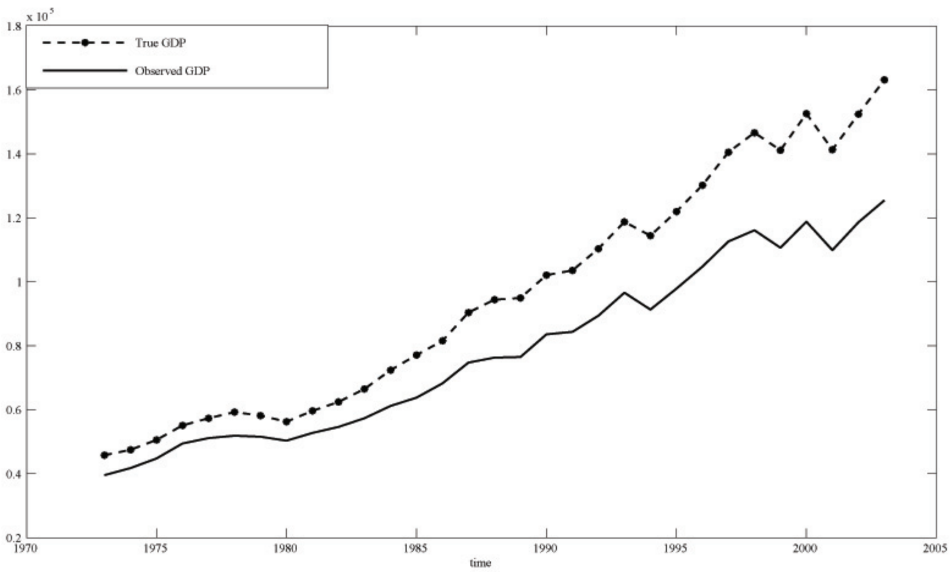

FIG. 2.1 – Plot of the level of the *true* GDP and the level of the *observed* GDP (YTL thousand at fixed (1987) prices).

From Fig. 2.1 it follows that the *true* GDP, given by the Kalman filter output, is fairly over the *observed* GDP and the gap between these variables is increasing with respect to time. Fig. 2.2 presents a graphical plot of the gap between the variables involved, expressed as percentage of the *observed* GDP, that is, the size of unrecorded economy in Turkey.

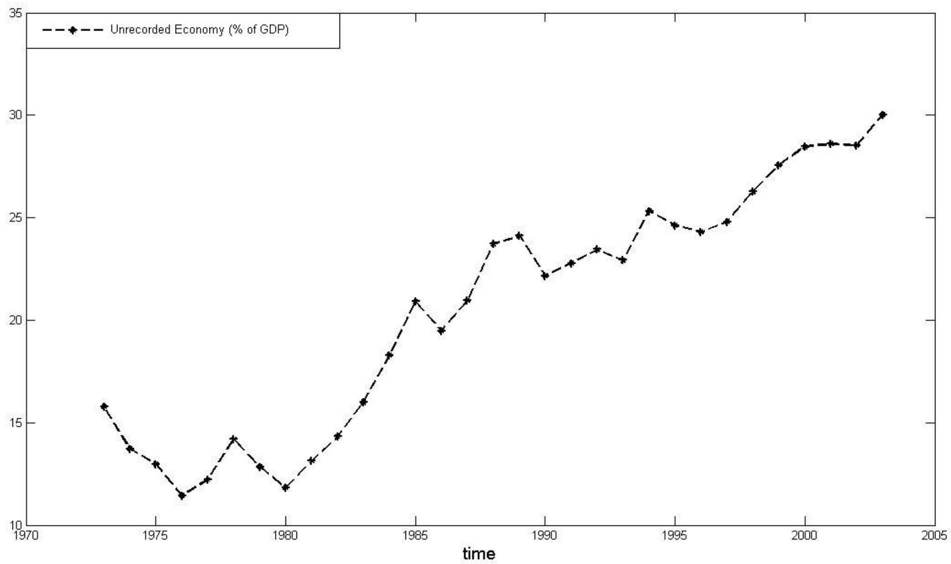

FIG. 2.2 – Size of unrecorded economy (% of the *observed* GDP)

During the 1973-1980 period, when the Turkish economy experienced a closed economy, the size of unrecorded economy is low, varying between 11 to 16 percent of the *observed* GDP.[8] This can be explained by the over estimation of GDP by the SIS in 1970s (Hatiboglu, 2004). On the implementation of the structural policies by the Turkish government in 1980, aiming at opening the economy and giving the market mechanism more room to function, the gap between *true* GDP and *observed* GDP grew in the following 23-year period and the size of unrecorded economy rose to 30 percent in 2003. Note that the objective of this study is to estimate the *true* GDP and the size of unrecorded economy in Turkey using CO_2 emissions. Even if

[8]Until 1980, Turkey followed an inward-oriented development strategy. About half of the industrial value added was created by state owned enterprises (SOEs) and Turkish manufacturing industries were protected by tariffs, quotas and over-valued exchange rates. See Togan (1996) for a detailed discussion on the institutional background of Turkey.

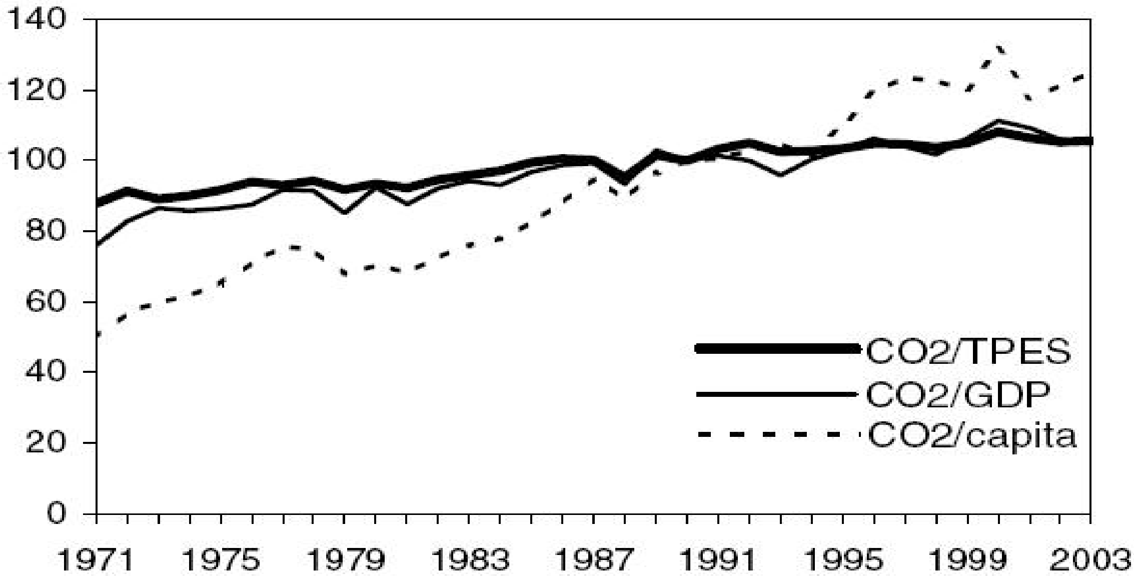

Fig. 2.3 – Energy-related carbon dioxide missions per GDP, per capita and per total primary energy supply (TPES)in Turkey (1990=100). Data source : IEA (2005a).

the ratio CO_2 emission per total primary energy supply (TPES) (i.e., $CO_2/TPES$ in Fig. 2.3) is a good indicator of the efficient usage of the primary energy sources in the industrialized economies ; handling this ratio as a unique indicator may lead to misinterpretations about the efficiency of production in the economies of the developing countries such as Turkey. In the case of Turkey, the reasons behind this intuition can be : first, the increase in CO_2 emissions is greater then the increase in TPES even if the carbon intensivity of total energy consumption did not increase over time[9] ; second, in the same period, the increase in GDP is equal to the increase in TPES ($GDP/TPES$ is constant). If one considers uniquely the ratio $CO_2/TPES$, one can conclude that the energy usage in Turkey becomes more carbon intensive in time.

[9]For detailed statistics on energy use in Turkey, see IEA (2005b, 2006).

However, if we take into account both the ratios, $CO_2/TPES$ and $GDP/TPES$, then it can be easily derived that the observed GDP in Turkey cannot be sufficient to cause relevant increase in carbon dioxide emission per total primary energy supply (i.e., $CO_2/TPES$). Thus, we will first show how this indicator is not convenient for Turkey and then we propose another measure for the energy efficiency and the size of unrecorded economy.

Table 2.6 gives some key indicators of energy use for three countries ; Germany, United Kingdom and Turkey. As in all industrialized countries, in Germany and United Kingdom while the ratio $CO_2/TPES$ is decreasing, GDP per TPES is increasing over time. On the other hand, this picture is reversed for the case of Turkey. For the Turkish economy, although GDP per TPES remains constant over time, the ratio $CO_2/TPES$ is increasing, which is not economically plausible. The intuition behind this is : after the production process, TPES (input) is transformed into CO_2 and the GDP (output). Thus, for given TPES, the higher the GDP, the lower the carbon emission, hence higher energy efficiency, and *vice versa*. Therefore, one should suspect the existence of a considerable size of unrecorded economy. Consequently, if our estimation results are taken into account, then this inconsistency disappears (Table 2.6).

4 Conclusion

In the present chapter, we have examined the size of unrecorded economy in Turkey using time series data for the 1973-2003 period. We analyzed first the characteristics of the time series of the variables involved. We performed non-stationary analysis and investigated whether GDP contains an autoregressive unit root or not,

TAB. 2.6 – Key indicators in energy use

$\frac{CO_2}{TPES}$ (million tonnes of CO_2 per petajoule)	1990	1995	2003	% change (1990-2003)
Germany	64.8	61	58.7	-9.3
United Kingdom	63	57	55.6	-11.8
Turkey	58	60	61.3	5.7
$\frac{GDP}{TPES}$ (thousand 1995 US$ (using exch. rates) per petajoule)	1990	1995	2003	% change (1990-2003)
Germany	103.7	119.6	129.8	25.1
United Kingdom	127	132	157.7	24.1
Turkey	63.7	63.1	63.7	0
Turkey*	77.1	78.5	82.7	7.2

*Our estimations

and then derived the state equation from the OLS estimation. Secondly, in order to determine the observation equation, we checked the long-run properties between CO_2 emissions, GDP, population and forest area. The estimated cointegrating vector suggests that there is a long-run relationship among these variables.

The study presented in this chapter contributes to the literature, first, by employing the Kalman filter technique in the estimation of the size of unrecorded economy and, second, by using two environmental variables, CO_2 emissions and forest area, and a social variable, country population, for the estimation of a purely economic indicator–the size of unrecorded economy. We found out that the size of unrecorded economy is varying between 12 and 30 percent over the period 1973-2003. The conventional estimation methods give for the relevant variable an estimation of about 6-45 percent of the GNP, which is relatively consistent with our findings.

In general, our results support the view that the size of unrecorded economy has considerably increased, especially after the implementation of a new reform program by the Turkish government on February 14, 1980 with adoption of open economy strategy instead of closed economy. Once more we have to repeat that the inconsistency between the change in the GDP per TPES and that of CO_2 per TPES shows the existence of unrecorded economy. Moreover, this inconsistency is eliminated by considering the size of unrecorded economy that this study estimates. Also, it is obvious that increasing TPES could increase the future size of Turkish unrecorded economy.

Finally, we would like to mention a recent development in the system of national accounts in Turkey. GDP series used in this chapter (as well as in all other chapters of this thesis) are obtained from the Central Bank of Turkish Republic which provides estimates of several macroeconomic variables from Turkish Statistical Institute (TurkStat). In order to estimate GDP series the latter was using the System of National Accounts of the United Nations (SNA 68). Since 2007, jointly with the Central Bank and the Ministry of Finance, TurkStat works on a new accounting system called European System of National and Regional Accounts (ESA 95). This development is due to the process of adaptation to the European Union (or EU harmonization process). Besides, adopted by the Council of the European Union in June 1996, ESA 95 has the principal objective of arriving "*at a consistent, reliable and comparable quantitative description of the economies of the Member States*".[10] The main differences between SNA 68 and ESA 95 come from the improved classifi-

[10] All concepts, definitions, classifications and accounting rules used in ESA 95 are available on the web site of CIRCA (Communication and Information Resource Centre Administrator) : http ://circa.europa.eu/irc/dsis/nfaccount/info/data/ESA95/en/esa95en.htm.

Tab. 2.7 – Comparison between the two estimation results

Years	$\frac{TGDP-OGDP}{OGDP} \times 100$*	$\frac{GDP_{ESA95}-GDP_{SNA68}}{GDP_{SNA68}} \times 100$**
1998	26.27	31.16
1999	27.56	26.13
2000	28.46	30.36
2001	28.60	27.68
2002	28.52	25.97
2003	30.01	26.79

*Our estimations

**Calculations based on the estimation results from TurkStat.

cation and extended scope of economic activities accounted for. To be more precise, intersectoral flows (especially between industry and construction) are taken into account, new agricultural and animal products are included, household labor force surveys are also used (for example, in 2002 recorded employment in the manufacturing industry was 2,133,644, whereas according to the results of the household labor force survey, it is 3,545,163), other economic activities (for example, personal services, security, cleaning, gardening, etc.) are also included in the new system. As a result, the new GDP (GDP_{ESA95}) is higher than the old one (GDP_{SNA68}) in the whole period of observation (1998-2006) and the difference between these two series varies between 26 and 37 percent of the latter.

Table 2.7 is given in order to make a comparison between our estimation results for the size of unrecorded economy and the difference between the new and the old GDP series calculated by TurkStat. One should be careful when reading and interpreting Table 2.7, since the values given in the third column of the table do not represent, *stricto sensu*, the size of unrecorded economy. We see clearly that the difference between GDP_{ESA95} and GDP_{SNA68}, expressed in percentage of the latter, is more volatile than the estimated size of unrecorded economy. On the other hand, for the years 1999 and 2001 our estimation results are slightly higher than the $\frac{GDP_{ESA95}-GDP_{SNA68}}{GDP_{SNA68}}$ ratio, while the difference between them is maximum about 4.9 percent in 1998. Therefore we may conclude that, in general, the revision made in the system of national accounts in Turkey validates our findings in this chapter.

At the end of this chapter we should point out that the aim of this chapter was to provide an alternative estimation method for the size of unrecorded economy, which can be qualified as "environmental estimation of unrecorded economy" and that it was well beyond our purposes in this chapter to test for a long-run relationship between energy consumption and *true* GDP. Furthermore, we have not yet discussed whether *true* GDP series estimated in this chapter are appropriate for a cointegration test with energy consumption or not. The next chapter will deal with these issues in more detail and will try to test variability of the results obtained in a GDP-energy consumption nexus once unrecorded activities are accounted for, thereby completing the empirical analysis of this thesis.

5 Appendix A. Calculation of CO_2 emissions from fuel combustion : IPCC methodology

The presentation of the methodology used for the estimation of CO_2 emissions developed on a set of publications from IPCC and IEA (2005a, 2007b). The estimation process consists of six consecutive steps. In what follows we expose each of these steps.

1. First of all, total fuel supplied (or apparent consumption (AC)) is estimated. For this purpose following formula is used :

   AC = Production + Imports - Exports - International Bunkers - Stock Change

2. Energy consumption data for all energy sources are converted to a common energy unit. In order to do so, the AC is multiplied by the relevant conversion factor to obtain all data in terajoules (TJ).

3. In the next step, the AC in TJ is multiplied by the carbon emission factor to obtain the carbon content in tonnes of carbon (tC). Naturally, each fuel has a different carbon emission factor. To give some examples, in terms of tC/TJ, the carbon emission factor is : for lignite, 27.6 ; for crude oil, 20 ; for jet kerosene, 19.5 ; for LPG, 17.2.

4. Net carbon emissions are then calculated by subtracting the values for carbon stored from carbon content estimated in the previous step. On the other hand, in order to calculate carbon stored, fuels are distinguished into three groups : bitumen and lubricants ; coal oils and tars ; natural gas, LPG, ethane, naphtha and gas/diesel oil. The amount of these fuels used for energy purposes is calculated. For instance for coking coal, the default assumption is that 6% of the carbon in coking coal consumed is converted to oils and tars. As a result, the AC for coking coal should be multiplied by 0.06.

5. The next step consists of correcting for carbon unoxidised. For this, net carbon emissions are multiplied by fraction of carbon oxidised. Once again, for each type of fuel fraction of carbon oxidised may be different. For example, for different types of coal it varies between 0.91 and 0.98, for gas it is 0.995. The results obtained give the actual carbon emissions.

6. The final step is converting actual carbon emissions to CO_2 emissions by mul-

tiplying the former by 44/12 (which is the molecular weight ratio of CO_2 to C). Taking the sum gives total national emissions of carbon dioxide from fuel combustion.

6 Appendix B. Stationarity tests

Tab. 2.8 – Results of unit root tests

Variable	Augmented Dickey-Fuller (ADF)		Phillips-Perron (PP)	
	Levels	First differences	Levels	First differences
GDP	-2.536	-6.239	-2.675	-6.265
CP	1.538	-0.810*	0.593	-1.012*
CO2	-3.122	-6.995	-3.125	-7.266
Critical values				
1%	-4.334	-3.723	-4.334	-3.723
5%	-3.580	-2.989	-3.580	-2.989
10%	-3.228	-2.625	-3.228	-2.625

*The null hypothesis of non-stationarity cannot be rejected for the first difference of the variable CP. Taking the second difference, ADF test statistic is -4.373 and PP test statistic is -4.368 for both of which the 5 percent critical value is -2.992.

Chapitre 3

Energy consumption and economic growth revisited : Does the size of unrecorded economy matter ?

1 Introduction and related literature

Up to this point in our study on the energy-income nexus, the major criticism outlined (i.e. existence of unrecorded economy) calls for a new analysis of the problem. Karanfil [Karanfil, F. (2008). "Energy consumption and economic growth revisited : Does the size of unrecorded economy matter ?", *Energy Policy*, 36 (8), 3019-3025.] is the only reference on the subject one can find in the literature. This chapter presents *in extenso* this study providing also some supplementary materials in Appendixes which are not given in the original manuscript.[1]

Since the pioneering work of Kraft and Kraft (1978) the relationship between energy consumption and economic growth is studied by many authors using various methodologies for different time periods. Nevertheless, studies that have tested the causality between these two variables reveal conflicting results on the issue. This is mainly due to the fact that estimation results are very sensitive to the time period considered, the country and the methodology employed. To test for a long-run relationship the cointegration technique developed by Engle and Granger (1987) is used in many studies within the last two decades. If two or more variables are cointegrated then we can conclude that there is a long-run equilibrium relationship between these variables. In this case, using a vector error-correction model (VECM), Johansen (1991) and Johansen and Juselius' (1990) maximum likelihood procedure can be applied to test for the direction of Granger causality (Granger, 1988). In the absence of cointegration, that is, no long-run relationship can be established, no

[1] Since this Ph.D. thesis consists of a series of essays written at different times, even though some of the methodological issues presented in this chapter have already been discussed in the previous chapters, they have all been retained here in order to maintain the integrity of Karanfil's (2008) study.

error-correction mechanism binds the non-cointegrated variables and the Granger causality test is applied in a vector autoregression (VAR) context instead of a VECM.

In the literature regarding the causal relationship between energy consumption and economic growth in Turkey, many studies have found inconsistent results. Using a VECM, Soytas and Sari (2003) found a long-run unidirectional causality running from energy consumption to gross domestic product (GDP) per capita. However, using the endogenous break unit root tests proposed by Zivot and Andrews (1992) and Perron (1997), Altinay and Karagol (2004) argued that a spurious causality would exist between the series if the data are mistreated as integrated of order one. Investigating the period of 1950-2000, they showed that both the GDP and energy consumption series in Turkey are trend stationary with a structural break and found no evidence of causality between energy consumption and GDP in Turkey based on the detrended data. On the other hand, using annual data over the period 1970-2003, Lise and Van Montfort (2007) found recently that in Turkey, energy consumption and GDP are cointegrated and the direction of causality is running from GDP to energy consumption. Again for the case of Turkey, in a very recent study, Jobert and Karanfil (2007) using annual time series for the period 1960-2003 argue that in the long run, income and energy consumption are neutral with respect to each other at both the aggregate and industrial levels. Their study reveals also a strong evidence of instantaneous causality, which means that contemporaneous values of energy consumption and income are correlated.

In a large number of studies inconsistent results concerning the direction of the relationship have been found for different countries : e.g. for different time periods, in India the direction of causality is from energy to income (Asafu-Adjaye, 2000 ; Masih and Masih, 1996). However, Paul and Bhattacharya (2004) found bidirectional causality for the same country. On the other hand, empirical studies focusing on some industrialized countries give disparate estimations ; e.g. Kraft and Kraft (1978) found a significant causal relationship between income and energy consumption in the case of the United States for the period 1947-1974, supporting the view that income Granger causes energy consumption. However, Stern (2000), using a VAR model, pointed out that the direction of causality runs from energy consumption to income in the United States.

Some recent studies have also employed the dynamic panel data approach to investigate the energy-income nexus in both developed and developing countries. For example, using the panel data for 40 countries (22 developed and 18 developing countries), Lee and Chang (2007) showed that there exist a unidirectional causal relationship running from GDP to energy consumption in the developing countries and a bidirectional causality (or feedback) in the developed countries. However, Huang et al. (2008) extended the data to cover 82 countries, which are divided into four categories based on the income levels defined by the World Bank, and they reported that economic growth leads energy consumption positively in the middle income group and negatively in the high income group. They also find no evidence of causality from energy consumption to economic growth in any of the four income groups. Moreover, their VAR model includes other control variables such as pollution level and the share of value added in industry to GDP, since the Granger causality test in a bivariate framework may be subject to the omitted variables bias (Lutkepohl, 1982). Multivariate systems are also used in some recent country-specific case studies. For example Hondroyiannis et al. (2002), employing a trivariate model to analyze the dynamic relationship between energy consumption, income and price level, found that in the long run, energy consumption and economic growth are interrelated in Greece. Again in a trivariate system but using pollutant emissions instead of prices, Ang (2007, 2008) draws the conclusion that economic growth exerts a causal influence on energy use both in France and Malaysia, respectively. In the same framework, Soytas and Sari (forthcoming) using the data on the Turkish economy over the years 1960-2000, pointed out that income and emissions are neutral with respect to each other and that emissions Granger cause energy consumption. In the light of these results, they concluded, as did Jobert and Karanfil (2007) before them, that an energy-saving program can be followed without harming economic growth and that investments on energy technologies should be undertaken in order to switch to less carbon-intensive energy use in Turkey.[2]

We have to also point out that the past studies mentioned above have not examined whether there exist unrecorded (or unreported) economic activities that contribute to the energy use. In a country if the unrecorded economy has an important weight in the overall economic activities then a significant part of the energy use does not seem to create any value added in the officially calculated GDP. That is certainly the case for most of the developing countries. Thus, the investigation of the linkage between energy consumption and official GDP may not give reliable results in such countries.

Smith (1994) gives the definition of underground or shadow economy as "market-based production of goods and services, whether legal or illegal that escapes detection in the official estimates of GDP".[3] There is a large literature on estimating the size of unrecorded economy. Surveys based on household data (direct or micro approach) as well as macroeconomic indicators such as GDP, employment or aggregate

[2]Additional empirical results from causality tests for other developing and industrialized countries can be found in Lee (2005, 2006) and Chontanawat et al. (2008).

[3]See Feige (1990) for a detailed classification of underground economic activities.

currency demand (indirect or macro approach) are commonly used in the relevant literature.

Although the size of unrecorded economy varies in different periods and across different countries, developing countries have fairly the largest unrecorded economies with 44% in African countries and 39% in Latin American countries. Regarding transition and developed countries, unrecorded economy is estimated to account for 20% in Middle and Eastern European countries and for 12% in OECD countries (Gerxhani, 2004). Concerning the Turkish unrecorded economy, the results have been mixed depending not only on the methodology but also on the period considered. Table 3.1 summarizes the results of the main studies on the size of unrecorded economy in Turkey.

TAB. 3.1 – The comparison of empirical results on the size of unrecorded economy in Turkey

Authors	Method or Approach	Period	Size of Unrecorded Economy
Temel et al. (1994)	Transaction approach	1970-1992	0-26% of the official GNP
Temel et al. (1994)	Tanzi's econometric approach	1975-1992	6-20% of the official GNP
Ogunc and Yilmaz (2000)	Currency demand approach	1971-1999	11-22% of the official GNP
Cetintas and Vergil (2003)	Tanzi's econometric approach	1971-2000	18-30% of the official GNP
Savasan (2003)	MIMIC Model	1970-1998	10-45% of the official GDP
Schneider and Savasan (2007)	DYMIMIC Model	1999-2005	32-35% of the official GDP
Karanfil and Ozkaya (2007)	Environmental method	1973-2003	12-30% of the official GDP

As it can be seen from Table 3.1, there are several methods used in the estimation of the size of unrecorded economy. According to the transaction approach (Feige, 1979), the difference between nominal GNP and total transactions gives the size of unrecorded economy. On the other hand, the intuition behind the currency demand approach (Cagan, 1958) is that an increase in the tax burden may increase the size of informal economy as well as the currency demand since the unrecorded economic activities are paid in cash. Tanzi's (1983) econometric approach is used to detect the variations in the size of unrecorded economy after a tax rise. In the multiple indicator multiple causes (MIMIC) model (Frey and Weck, 1983a, b) various macroeconomic variables are introduced to estimate the size of unrecorded economy. All of these methods have advantages and weaknesses, which are well documented in the literature (Frey and Pommerehne, 1984 ; Feige, 1990 ; Thomas, 1999). Overall empirical results indicate that in Turkey unrecorded economic activities represent a large part of the economy varying between 0% and 45% of annual output.[4] It is then obvious that total energy supply in Turkey is not entirely used in the recorded economic activities ; thus the linkage between official GDP and energy consumption in Turkey is very critical.

The purpose of this chapter is to empirically re-examine the causal relationship between energy consumption, officially calculated GDP and *true* GDP, that is, the sum of unrecorded economy and official GDP in Turkey. To the best of our

[4]To avoid any ambiguity in considering Table 3.1, notice that the fourth column of the table displays the minimum and maximum values for the size of unrecorded economy calculated for different years in different studies. For example, Karanfil and Ozkaya (2007) report that for the period 1973-2003 the size of unrecorded economy in Turkey is at its minimum in 1976 with 12% of the offical estimate of GDP while the maximum value of 30% is reached in 2003. Other estimates in the table should be interpreted in this context, thus no concern exists here regarding for instance confidence intervals.

knowledge, no study has proposed such an analysis for any country. The results of this chapter will improve our understanding of the relationship between energy consumption and recorded and/or unrecorded economic activities. Therefore they have important policy implications for Turkey.

The remainder of the chapter is organized as follows. In Section 2, we briefly describe the methodology employed and the data used in the empirical analysis. In Section 3, we present the empirical results and the final section contains the conclusions and the policy implications.

2 Data description and econometric methodology

In a very recent study, Karanfil and Ozkaya (2007) developed a new methodology to estimate the size of unrecorded economy. Employing the Kalman filter technique and using economic variables (GDP and country population) as well as environmental variables, namely carbon dioxide (CO_2) emission and forest area, they estimated the unrecorded economy in Turkey to be 12-30% of the GDP for the period 1973-2003. The intuition in their paper is that energy is essential to economic growth and *ipso facto*, energy use leads to CO_2 emission. Thus, emission level can be a good indicator of both recorded and unrecorded economic activities. However, although their idea is promising, we think that the *true* GDP series from their study are not appropriate for a cointegration test with energy consumption. In our view, the reasons for this are clear. First, their model uses CO_2 emission that is calculated by using the Intergovernmental Panel on Climate Change (IPCC) method (see *supra* Annexe A in Chapter 2 for the methodology used in the estimation of CO_2 emissions). This is an important limitation since it is obvious that CO_2 emission level would be higher if it is measured in the atmosphere, that is, larger size of unrecorded economy. Consequently, the estimation of unrecorded economy in Karanfil and Ozkaya (2007) should be taken as "at least estimation". Besides, as discussed in the previous chapter, CO_2 emissions are based on the *official* energy consumption data, which raises and important caveat for the estimation of unrecorded economy. Second, and more important, as from the equation established by the authors (observation equation) they estimate the *true* GDP data using CO_2 emissions ; these data will be *a fortiori* correlated with energy consumption data. As a result, tests for cointegration between energy consumption and the *true* GDP series obtained from their study will likely be biased.[5] We believe that among the other methods cited in Table 3.1, the model approach (or (DY)MIMIC) gives the most reliable estimations of the size of unrecorded economy as it considers explicitly both the multiple causes (such as tax revenue collected as percentage of tax filed, unemployment rate, real per capita disposable income, inflation, etc.) and its multiple effects in the production, labor and money markets over time.[6] In our study, the data used for unrecorded economy to obtain the variable *true* GDP (henceforth TGDP) is the product of the estimations of unrecorded economy based on the model approach from Savasan (2003) and Schneider and Savasan (2007). Further, as their model does not involve any energy-related variable, their estimations seem to be more appropriate for the

[5]High degree of correlation between these two series (*true* GDP from Karanfil and Ozkaya (2007) and energy consumption has been proved in cointegration and causality tests. Results from these tests show clearly a bidirectional causality between the relevant variables. These results are not reported in this document since they are spurious.

[6]See Joreskog and Goldberger (1975) for a detailed description of the procedures for estimation of a latent variable from a MIMIC model. See also the pioneering study of Frey and Weck (1984) for the use of MIMIC modeling in the context of unrecorded economy.

empirical tests conducted in this chapter.

The annual data for official real GDP (henceforth OGDP) are obtained from the Central Bank of the Republic of Turkey. The total (or aggregate) energy consumption (henceforth TEC) data are taken from the *Energy Balances of OECD Countries* published by International Energy Agency. The GDP series (OGDP and TGDP) are expressed in YTL (New Turkish Lira) at constant 1987 prices while the energy consumption is expressed in thousand tons of oil equivalent (ktoe). All data cover the sample period from 1970 to 2005. All variables are transformed into natural logarithms not only to reduce heteroscedasticity but also to obtain the growth rate of the relevant variables by their differenced logarithms.

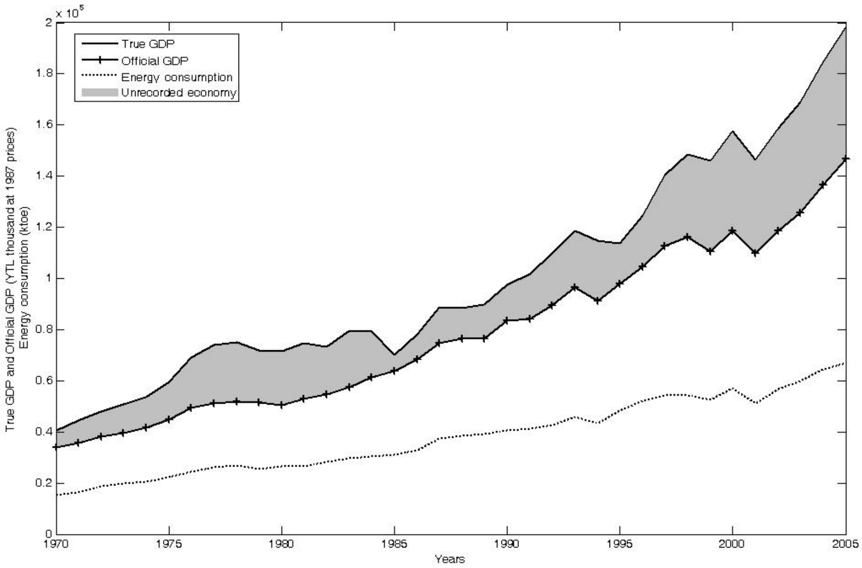

FIG. 3.1 – Total energy consumption, official GDP, *true* GDP and unrecorded economy in Turkey from 1970 to 2005 (before taking logarithms). Data sources : Savasan (2003), Schneider and Savasan (2007), IEA (2007) and Central Bank of the Republic of Turkey.

Fig. 3.1 shows the trends in TGDP, OGDP and TEC. All variables increased during the sample period. The gap between TGDP and OGDP, that is, unrecorded economy, reached its peak with 44.4% of OGDP in the late 1970s, which is accompanied by a big drop in the mid-1980s. Introduction of a value-added tax in 1985, which is accounted for in the MIMIC model as a dummy variable may have played a role in this drop (Savasan, 2003). The size of unrecorded economy in Turkey has been growing since 1995 and it is still very large (35.1% in 2005) ; however, its growth rate is decreasing in the last 10 years. On the other hand, OGDP and TEC series appear to have common trends while the relationship between TGDP and TEC seems to be less clear.

As we have already mentioned in the previous chapter, at this point, we would like to make some critical comments on the energy consumption data used in the analysis conducted here. An important caveat for our study is that in Turkey these data provided by IEA (which is in fact supplied by Turkish authorities) do not take into account illegal energy use, such as stealing electricity or illegal export of diesel fuel. It is possible that both recorded and unrecorded economic activities consume this *illegal* (unrecorded or undeclared) energy. In other words, energy consumption in economic activities may be a blending of *illegal* and *legal* energy use. To further comment on this point, let us, for example, take the case of electricity consumption. Final consumption of electricity is calculated by deducting both transmission and distribution losses (TDL) and energy sector consumption from electrical energy supplied (EES) with *EES=net production+imports-exports*. Let us now suggest a ratio that we may call "electricity supply efficiency ratio" (ESER) and define it in the following fashion :

$$ESER = \frac{TDL}{EES} \times 100$$

This ratio in Turkey is far higher than that of other OECD countries. For instance, in 2003 it is about 17.7 while the average of OECD countries is 7.3 and the average of European Union-15 countries is about 6.6 (own calculations from IEA (2005c)). It is evident that in Turkey, electric transmission lines are somewhat responsible for this high ratio. On the other hand, stealing electricity has also an important role. However this behavior may be related more to the residential energy consumption (especially for the purpose of house heating by by-passing meters or by laying out an electricity line from public street lamps). That is to say, an important part of stealing electricity does not crate any value added, thus may not influence our results. Of course, it would be much better if we had a measure of stealing electricity in the industrial or service sectors.

We now proceed with our econometric analysis, but of course the discussion remains open.

Before we test for a long-run equilibrium relationship between the variables, since cointegration regressions require non-stationary data of the same order of integration, we first perform the augmented Dickey Fuller (ADF ; Dickey and Fuller, 1981) and the Phillips and Perron (PP ; Phillips and Perron, 1988) unit root tests based on the following model :

$$\Delta X_t = \mu_0 + \eta t + \mu_1 X_{t-1} + \sum_{i=1}^{k} \lambda_i \Delta X_{t-i} + u_t \tag{3.1}$$

where X is the variable to be tested, t is the trend variable, Δ is the first-difference operator and u_t is Gaussian white noise. The Akaike information criterion (AIC) is used to choose the lag length k.

If the variables are integrated of the same order the next step will consist of testing for cointegration among the variables. As it is shown in Engle and Granger (1987), any combination of two series I(1) may be stationary, that is, I(0) and in this case, we can conclude that there exists a long-run equilibrium relationship between these variables. In our model this interpretation can be expressed more formally as follows :

$$a_1 OGDP_t + b_1 TEC_t \sim I(0)$$

or

$$a_2 TGDP_t + b_2 TEC_t \sim I(0)$$

Then we can have the following two equations :

$$\begin{aligned} OGDP_t &= \varphi_1 + \gamma_1 TEC_t + e_{1t} \\ TGDP_t &= \varphi_2 + \gamma_2 TEC_t + e_{2t} \end{aligned} \tag{3.2}$$

where e_{1t} (e_{2t}) represents equilibrium error. The existence of cointegration between the relevant variables rules out Granger non-causality and the causality test should be performed in a VECM.

In the case of non-cointegration the Granger causality test will be performed in a first-differenced VAR framework. We discuss the Granger causality methodology according to the results obtained in the next section.[7]

3 Empirical results

In this section we first deal with the relationship between GDP (both TGDP and OGDP) and energy consumption, and then we examine the variability of the results once gross national product (GNP) is used as the economic variable instead of GDP. This analysis will give us the opportunity to compare the results of this section with those reported in the first chapter of this thesis.

[7] Detailed discussion of the cointegration and Granger causality procedure can be found in Hamilton (1994, chapters 11 and 19).

3.1 GDP-energy nexus

Table 3.2 reports the results for both the ADF and PP unit root tests.

Tab. 3.2 – Results of unit root tests

Variable	Augmented Dickey-Fuller (ADF)		Phillips-Perron (PP)	
	Levels	First differences	Levels	First differences
OGDP	-2.924	-6.431	-2.946	-6.430
TGDP	-2.625	-5.312	-2.744	-5.313
TEC	-3.484	-6.484	-3.460	-6.484
Critical values				
1%	-4.288	-3.689	-4.288	-3.689
5%	-3.560	-2.975	-3.560	-2.975
10%	-3.216	-2.619	-3.216	-2.619

From Table 3.2 it can be seen that the null hypothesis of non-stationarity cannot be rejected for the levels of the variables. However, when we take the first differences, the null hypothesis of non-stationarity is rejected at the 5% level of significance. On the other hand, final prediction error, AIC, the Schwarz information criterion and the Hannan-Quin (HQ) information criterion suggest that 1 lag should be chosen for the level of each variable (0 lag for differenced variables). Furthermore, for all variables, recursive estimations of the lagged first differences in Eq. (3.1) suggest that the specification of the lag length given by the above-mentioned criteria is robust. Thus, we can conclude that all the variables involved are integrated of order one, that is, I(1).

Since all the variables are I(1) we can test whether there exists any cointegrating relationship among them. We use Johansen and Juselius' (1990) maximum likelihood approach employing both the maximum eigenvalue and trace statistics to test for cointegration. Table 3.3 summarizes the results.

TAB. 3.3 – Johansen Test for the number of cointegrating relationships

	Eigenvalue	$H_0 : r$	Trace	L Max	Critical values at 95%	
					Trace	L Max
OGDP-TEC Model	0.3792	0	16.88	16.69	15.41	14.07
	0.0055	1	0.19	0.19	3.76	3.76
TGDP-TEC Model	0.1124	0	6.68	4.17	15.41	14.07
	0.0692	1	2.51	2.51	3.76	3.76

r indicates the number of cointegrating relationships. The critical values for maximum eigenvalue and trace test statistics are given by Johansen and Juselius (1990). The specification for both TGDP-TEC and OGDP-TEC models includes an intercept and no trend in the cointegrating equations.

Cointegration test results lead us to conclude that a long-run relationship between TGDP and TEC does not exist. However, both the trace and the maximum eigenvalue tests indicate 1 cointegrating relation with 95% confidence level between OGDP and TEC. In order to check the robustness of the results the Engle and Granger (1987) two-step procedure is also conducted.[8]

As we found that OGDP and TEC are cointegrated, a VECM should be estima-

[8]We have also tested for a cointegrating relationship between unrecorded GDP and energy consumption and the results imply that there is no long-run relationship between these two variables. Results are given in Appendix A.

ted rather than a VAR as in a standard Granger causality test (Granger, 1988) :

$$
\begin{aligned}
\Delta OGDP_t &= \psi_1 + \sum_{i=1}^{p} g_i \Delta OGDP_{t-i} + \sum_{i=1}^{n} h_i \Delta TEC_{t-i} + \alpha_1 \epsilon_{t-1} + u_{2t} \\
\Delta TEC_t &= \psi_2 + \sum_{j=1}^{n} q_j \Delta TEC_{t-j} + \sum_{j=1}^{p} r_j \Delta OGDP_{t-j} + \alpha_2 \epsilon_{t-1} + v_{2t}
\end{aligned}
\tag{3.3}
$$

where ϵ_{t-1}, the error correction term, is the lagged estimated residual from Eq. (3.2). The error term e_{1t} in Eq. (3.2), which is found to be stationary (reported in Appendix B), measures the deviations of OGDP and TEC from their long-run equilibrium relationship.

Again a recursive estimation of model parameters is conducted. The results of the VECM given in Eq. (3.3) are reported in Table 3.4.

According to F-statistics of the lagged explanatory variables, *official* economic growth and energy consumption found to be neutral in the short term. In order to analyze the long-run causal relationship, we test for weak exogeneity among the cointegrating relationship using a likelihood ratio test (LR), which follows a χ^2 distribution. We see that the error-correction term in the OGDP equation is not significant while in the TEC equation it is significant at the 1% level. This implies that energy consumption and official GDP interact in the short term to restore long-run equilibrium after a deviation of energy consumption from the long-run equilibrium relationship. Using F-test, the interaction terms (i.e. ϵ_{t-1} and the lagged explanatory variables) are also found to be statistically significant in the TEC equation, implying that there is a unidirectional Granger causality running from OGDP to TEC in both the short and long runs. Thus, we can conclude that a high level of growth of registered economic activities leads to high level of energy consumption.

Although according to the results of cointegration analysis we cannot reject the

TAB. 3.4 – Temporal Granger causality test results

OGDP-TEC model	Sources of causation				
	Short-run		Long-run	Joint (short-run/long-run)	
	F-statistics		LR-statistics	F- statistics	
	OGDP	TEC	ϵ_{t-1}	OGDP,ϵ_{t-1}	TEC,ϵ_{t-1}
OGDP equation	-	0.62	0.48	-	0.44
TEC equation	1.16	-	10.27**	5.38**	-

**Significance at the 1% level.

null hypothesis of no long-run relationship between TGDP and TEC, we can still determine the short-run dynamics by using a VAR model with two non-stationary and non-cointegrated variables. We search for a causal relationship between the relevant variables by applying Granger's (1969) causality procedure.[9] For this purpose, the next step in our empirical analysis involves estimating the following equations :

$$\begin{aligned} \Delta TGDP_t &= \delta_1 + \sum_{i=1}^{m} a_i \Delta TGDP_{t-i} + \sum_{i=1}^{n} b_i \Delta TEC_{t-i} + u_{1t} \\ \Delta TEC_t &= \delta_2 + \sum_{j=1}^{n} c_j \Delta TEC_{t-j} + \sum_{j=1}^{m} d_j \Delta TGDP_{t-j} + v_{1t} \end{aligned} \tag{3.4}$$

where u_{1t} and v_{1t} are white noise series, δ_1 and δ_2 are constant terms and m and n

[9]Granger's (1969) causality test is based on stationary series. However, Granger's (1988) study results show that the test remains valid with non-stationary and non-cointegrated variables, if the variables are differentiated. Furthermore, Toda and Phillips (1994) and Toda and Yamamoto (1995) propose another procedure to perform the Granger causality test with non-stationary and cointegrated variables. Somme additional information about this methodology and results from the test for Granger-causality applying Toda and Yamamoto's (1995) methodology are provided in Appendix C.

are the maximum number of lags assigned on the basis of both minimizing AIC and significance of lagged first differences.

Now we can use the standard F-test in order to test for the lack of Granger causality of TEC on TGDP. According to Eqs. (3.4) the null hypothesis that TEC does not Granger cause TGDP cannot be rejected if the coefficients b_i are all equal to zero. More formally the hypothesis of the test can be expressed as follows :

$$\begin{aligned} H_0 &: b_i = 0 \quad \forall i = 1,..,n \\ H_1 &: \exists b_i \neq 0 \quad \forall i = 1,..,n \end{aligned} \tag{3.5}$$

Similarly, we can say that TGDP does not Granger cause TEC if all d_j are zero. On the other hand, if the innovations u_{1t} and v_{1t} in Eq. (3.4) are correlated we can conclude that there is an instantaneous causality between TGDP and TEC. Table 3.5 gives the P values for the non-causality tests as well as the signs of the estimated coefficients.

Tab. 3.5 – P values of the Granger non causality tests

		Causality	TGDP	TEC
TGDP-TEC model	TGDP equation	Granger	0.79(+)	0.11(-)
		Instantaneous	-	0.00(+)
	TEC equation	Granger	0.78(-)	0.16(+)
		Instantaneous	0.00(+)	-

(-) Indicates that the sum of the coefficients is negative.

(+) Indicates that the sum of the coefficients is positive.

When we re-arrange the equations in the above given VAR model including also 0 lag for independent differenced variables, we obtain for example for the TGDP equation :

$$
\begin{aligned}
TGDP_t = \quad & \delta_1 + \beta_1 TEC_t + (-\beta_1 + b_1) TEC_{t-1} - b_1 TEC_{t-2} \\
& + (1 + a_1) TGDP_{t-1} - a_1 TGDP_{t-2} + u_{1t}
\end{aligned}
\tag{3.6}
$$

Thus, in Table 3.5, the signs of the sum of coefficients $((-\beta_1 + b_1)$ and $(1 + a_1))$ are given in order to see the impacts of the past values of energy consumption on the TGDP, vice versa for the TEC equation.

It can be seen from Table 3.5 that the F-statistic for the null hypothesis of no Granger causality from TGDP to TEC for the coefficient restriction given in Eq. (3.5) $b_i = 0$, as well as from TEC to TGDP, that is, $d_j = 0$, cannot be rejected at the 5% level, suggesting that TGDP and TEC are neutral with respect to each other. Furthermore, on the basis of recursive estimation of model parameters in Eq. (3.4), lagged first differences are found to be insignificant ruling out a short-term causal relationship between TEC and TGDP.[10] In other words, with no cointegration, this result implies that the energy consumption per unit of output (recorded and unrecorded) is not stable over the period from 1970 to 2005. This outcome contradicts the findings of previous studies on the subject (Soytas and Sari, 2003 ; Lise and Van Montfort, 2007), in which the size of unrecorded economy is neglected. However, we find that there is a unidirectional causal relationship between OGDP and TEC (Table 3.4) ; we may, therefore, reasonably conclude that there is no causal relationship between unrecorded economy and energy consumption in Turkey. Increasing size of unrecorded economy will have no effect on the energy consumption

[10] The results given here should be interpreted with caution, since, as noted by Lutkepohl (1982), Granger non-causality in a bivariate system may be due to an omitted variable. Thus, causality tests should also be performed in higher-order systems including other variables such as energy prices and capital stock. See Triacca (1998) who gives a theoretical proof of this fact.

in Turkey, and again in the long run energy policies implemented in the country will not affect the unrecorded economy, because the production function is not stable over time (i.e. no long-run equilibrium relationship exists).

On the other hand, there is strong evidence of instantaneous causality between TGDP and TEC (significance of β_1 in Eq. (3.6)), which indicates that contemporaneous values of energy consumption and TGDP are correlated.

3.2 GNP-energy nexus

As in other sections, we first check the stationarity of the variables. The results obtained using both the ADF and PP unit root tests for the variable GNP are reported in Table 3.6.

Tab. 3.6 – Results of unit root tests

Variable	Augmented Dickey-Fuller (ADF)		Phillips-Perron (PP)	
	Levels	First differences	Levels	First differences
GNP	-2.888	-6.339	-3.036	-6.334
Critical values				
1%	-4.288	-3.689	-4.288	-3.689
5%	-3.560	-2.975	-3.560	-2.975
10%	-3.216	-2.619	-3.216	-2.619

As the variable GNP is also found to be non-stationary in levels and stationary while first-differenced, we can proceed with our analysis by using GNP data with energy consumption data in the Johansen (1991) and Johansen and Juselius' (1990) maximum likelihood procedure. Table 3.7 gives the cointegration test results for the relevant variables.

TAB. 3.7 – Johansen Test for the number of cointegrating relationships

	Eigenvalue	$H_0 : r$	Trace	L Max	Critical values at 95%	
					Trace	L Max
GNP-TEC Model	0.3998	0	17.48	17.35	15.41	14.07
	0.0035	1	0.12	0.12	3.76	3.76

r indicates the number of cointegrating relationships. The critical values for maximum eigenvalue and trace test statistics are given by Johansen and Juselius (1990). The specification for GNP-TEC model includes an intercept and no trend in the cointegrating equations.

Once again, we found that GNP and TEC are cointegrated, that is, a long-run relationship can be established between these two variables. Thus, the next step consists of the determination of the direction of Granger causality using a VECM as presented in Eq. (3.3). The final results from such an analysis are shown in Table 3.8.

TAB. 3.8 – Temporal Granger causality test results

	Sources of causation				
	Short-run		Long-run	Joint (short-run/long-run)	
GNP-TEC model	F-statistics		LR-statistics	F-statistics	
	GNP	TEC	ϵ_{t-1}	GNP,ϵ_{t-1}	TEC,ϵ_{t-1}
GNP equation	-	0.43	0.10	-	0.24
TEC equation	0.77	-	6.33**	3.17*	-

The asterisks indicate the following statistical significance :**1%, *5%.

The results from Granger causality tests are very similar to those obtained in the OGDP-energy nexus. The long-run causality is found to be running from GNP to energy consumption in Turkey for the period 1970-2005. However, recall that, in the first chapter of this document, using the same methodology, we found no long-run relationship between GNP and aggregate energy consumption and concluded that these two variables are neutral with respect to each other over the period 1960 to 2003. Furthermore, conducting other tests to analyze disaggregate energy consumption we showed that GNP may be qualified as *forcing variable* for only electricity and petroleum products consumptions. Hence we may precise that the resulting inconsistency (causality between GDP (or GNP) and energy in Chapter 3 and no-causality between GNP and energy in Chapter 1) comes from the difference in the time periods considered. We think that the intuition for this result is clear : as we have discussed in Chapter 1, the 20-year period from 1960 to 1980 can be called as a capital accumulation period and this accumulation yielded a substantial change in the industrial production function by early 1970s, consequently, energy intensity in this sector increased considerably (see *supra* Fig. 1.4 in Chapter 1).

Moreover we see that it makes any difference whether GDP or GNP is chosen as an economic variable. This result should not surprise the reader since GDP and GNP are very close to each other in Turkey (see Fig. 3.2).

4 Policy implications and concluding remarks

In this chapter we study the Turkish energy-income linkage taking into account the size of unrecorded economy. Cointegration and Granger causality tests are conducted in two different models : with and without unrecorded economy. We find that there is a long-run equilibrium relationship between officially calculated GDP (or GNP) and energy consumption. In this case, we employed a VECM to test for Granger causality and we concluded that there is a long-run and joint causality

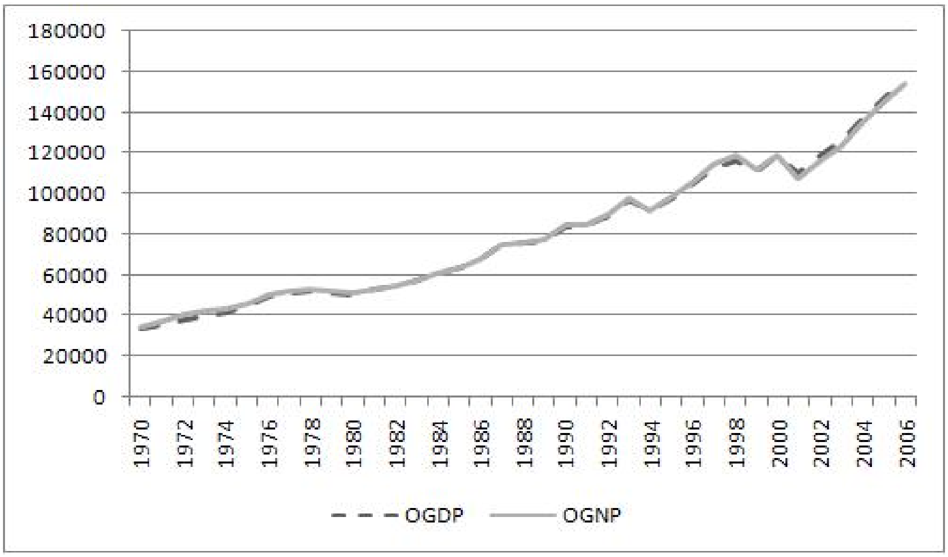

FIG. 3.2 – GDP and GNP in Turkey from 1970 to 2006 (YTL thousand at 1987 prices). Data source : Central Bank of the Republic of Turkey.

(in both short and long runs) from official GDP to energy consumption. However, when we take into account unrecorded economy, we employed a VAR model instead of a VECM, because we found strong evidence that the variables are not cointegrated. Empirical results suggest that TGDP and energy consumption are neutral with respect to each other.

These results could provide an answer to the question that we have posed in the present chapter : in the energy consumption-income nexus how does unrecorded economy matter ? While official GDP Granger causes energy use, the evidence in favor of neutrality of energy consumption with respect to TGDP signifies that energy consumption is fundamentally induced by recorded economic activities. Some key policy implications emerge from this finding. In order not to have problems in meeting energy demand in the future, an energy conservation policy may very well be feasible in Turkey without causing harm to official GDP. Such a policy may be achieved by a combination of regulatory measures and economic instruments such as energy-saving technical progress, energy taxes or subsidies like hydro, wind, solar and geothermal energy. However since energy taxes are heavily used in Turkey, raising them further does not seem to be economically justified. To give some examples, in January 2007, tax paid per liter of unleaded gasoline in Turkey was about 0.75 Euros (the highest tax rate in OECD countries) while it was, 0.6, 0.4 and 0.33 Euros in France, Spain and Greece, respectively. According to the official data reported by the Turkish Ministry of Finance, total tax paid is 57.68% (which is composed of 42.43% special consumption tax and 15.25% value added tax) for unleaded fuel, 46.3% for autogas, 44.98% for diesel fuel. For an extended international comparison and a more detailed information on the energy prices and taxes see IEA (2008).

On the other hand, we should also keep in mind that if environmental taxes are used without reducing the overall economic costs associated with the tax system, no double dividend occurs, hence the shift in tax burden, which is certainly the driving source behind the unrecorded economy, may increase the size of unrecorded economy. On the other hand, structural reforms and adjustment policies that should be implemented by Turkish governments aiming at decreasing the size of unrecorded economy may have no effect on the country's energy consumption in the long run. This is because according to our empirical results, energy input does not seem to be an essential factor of production in unrecorded activities. This conclusion is not surprising since unrecorded economy is generated by mainly tax evasion in economic activities like peddling or hawking.

Finally we must mention that the same analysis should be made for other developing countries in order to have some comparative results and then future research should focus on these issues to assess the generalizability of the results given in this study.

5 Appendixes

5.1 Appendix A. Unrecorded GDP-energy consumption model test results

TAB. 3.9 – Results of unit root tests

Variable	Augmented Dickey-Fuller (ADF)		Phillips-Perron (PP)	
	Levels	First differences	Levels	First differences
Unrecorded economy	-2.221	-5.898	-2.280	-5.972
Critical values				
1%	-4.288	-3.689	-4.288	-3.689
5%	-3.560	-2.975	-3.560	-2.975
10%	-3.216	-2.619	-3.216	-2.619

5.2 Appendix B. Stationarity tests for the error-correction term

5.3 Appendix C. Toda and Yamamoto augmented Granger causality test

According to Toda and Yamamoto (1995), in order to investigate the causal relationship between two variables, even if the series are not stationary, a VAR model in level can be estimated applying the standard Wald test. For this purpose,

TAB. 3.10 – Johansen Test for the number of cointegrating relationships

	Eigenvalue	$H_0 : r$	Trace	L Max	Critical values at 95%	
					Trace	L Max
TEC-Unrecorded economy model	0.1608	0	8.87	5.96	15.41	14.07
	0.0821	1	2.91	2.91	3.76	3.76

r indicates the number of cointegrating relationships. The critical values for maximum eigenvalue and trace test statistics are given by Johansen and Juselius (1990). The specification for TEC-Unrecorded economy model includes an intercept and no trend in the cointegrating equations.

we consider the following level VAR representation :

$$\begin{aligned} OGDP_t &= \sum_{i=1}^{c+k} \beta_{1i} OGDP_{t-i} + \sum_{i=1}^{c+k} \alpha_{1i} TEC_{t-i} + \mu_{1t} \\ TEC_t &= \sum_{j=1}^{c+k} \beta_{2j} TEC_{t-j} + \sum_{j=1}^{c+k} \alpha_{2j} OGDP_{t-j} + \mu_{2t} \end{aligned} \tag{3.7}$$

where c is is the maximum order of integration of the series in the system. Using Johansen and Juselius' (1990) maximum likelihood approach we have found that there exists one cointegrating relationship between the relevant variables, that is, we have $c = 1$ (see Table 3.3). On the other hand, k is the optimal lag order determined by AIC, and we have in our case $k = 1$. Error terms μ_{1t} and μ_{2t} are assumed to be white noise. Now, using the standard χ^2 statistics, conventional Wald tests can be applied to test the following hypothesis :

$$\begin{aligned} H_0 &: \alpha_{1i} = 0 \quad \forall i = 1,..,n \\ H_1 &: \exists \alpha_{1i} \neq 0 \quad \forall i = 1,..,n \end{aligned} \tag{3.8}$$

If the null hypothesis can be rejected, one may conclude that the variable TEC Granger causes $OGDP$. The same procedure should be applied for α_{2j} in order to

Tab. 3.11 – Results of unit root tests

Variable	Augmented Dickey-Fuller (ADF)	Phillips-Perron (PP)
	Level	Level
Error term e_{1t}	-4.443	-4.961
Critical values		
1%	-3.682	-3.682
5%	-2.972	-2.972
10%	-2.618	-2.618

test whether $OGDP$ Granger causes TEC or not. Test results are presented in Table 3.9.

Tab. 3.12 – Test for Granger-causality applying Toda and Yamamoto's methodology

Null hypothesis	χ^2 statistic	P value
TEC does not Granger cause OGDP	0.50	0.6132
OGDP does not Granger cause TEC	5.41	0.0099

Once again we find that while there is clear evidence of causality from $OGDP$ to TEC, lack of causality from TEC to GDP holds true. Consequently, this additional exercise confirms the robustness of the results presented in this chapter.

Chapitre 4

Optimal enforcement policy and firms' decisions on R&D and emissions : compliance versus cheating

1 Introduction and related work

So far, we have seen that in the case of Turkey the results from an empirical study are highly sensitive not only to the choice of sample period but also to the specification of the GDP variable (*observed* or *true*). Turning from these empirical analysis, in what follows, we move to a more theoretical discussion providing some interesting insights into the firm behavior subject to a variety of environmental regulation schemes. This is the first of two chapters dealing with the question of how environmental protection policy affects both production and investment decisions at the firm level. Chapter 4 is devoted to the optimal enforcement mechanism design while Chapter 5 places more emphasis on the possible relationship between environmental policy and the size of unrecorded economy. Some of the elements of the models presented here in Chapter 4 are also introduced into the next chapter's framework.

Although there exist no mechanisms for environmental policy which are without their problems, environmental economists have advocated emission taxes as an efficient means of controlling pollutant emissions.[1] The initial idea behind the environmental tax is to compensate for a damage created by the externalities at the

[1]Harmonization of economic and environmental goals is one of the main concern of policy makers. This has become crucial since the Kyoto Protocol, negotiated in December 1997, where countries committed to reduce their emissions of greenhouse gases and an enforcement branch is constituted to control the compliance of countries with their emission targets. There exists other instruments to reduce pollutant emissions : emission charges, emissions trading, performance bands, liability payments and noncompliance fees. In this chapter environmental taxes are considered since they emerge as potentially effective market instruments (see Watson et al. (1996)). Furthermore, Nellor (1997) argues that environmental taxes can replace taxes on labor since they imply lower social costs, thus using them may boost economic activity and promote employment.

production or the consumption processes, to control and regulate the level of the damage and to achieve environmental improvements. The latter can also be achieved through energy saving technical progress and clean energy technologies. In this context environmental taxation becomes also an instrument to encourage the innovation activities. Consequently, environmental improvement depends on an optimal and efficient taxation scheme so as to regulate the level of pollutant emissions and to provide incentives to innovate. However, in the emission taxes scheme, the regulator (or as it called in the literature, environmental protection agency (EPA)) needs to have full information in order to internalize external social damages created by the polluting firms. What if the regulator does not know the true emission level of each firm that it wishes to regulate? Then it must adopt an enforcement policy to achieve environmental standards. It is evident that such policies play a key role in the firms' decisions on both polluting emissions and technology choices. Thus, for policy makers, it is important to know how sensitive the behavior of firms is to different environmental regulation schemes.

On the other hand, the cost of determination of pollutant emission levels of agents by the enforcement agencies is high, thus self-reporting behavior may be benefit for the welfare of all.[2] So the self-reporting behavior becomes central in the regulation of negative externalities and the incentives for innovation and industrial growth. This chapter will explore the possibility that choosing an appropriate enforcement mechanism might create incentives for the firms to reduce polluting emissions and

[2]Not only auditing each agent (firms or households) is costly but also the cost of monitoring emission is very high. According to some older estimates, capital costs of a monitoring station that has a life time of ten years is about 20,000 to 30,000 euro per year. Adding operating costs, total costs for the monitoring station per year becomes in the range of 30,000 to 60,000 euro per year (Siebert, 2005).

to invest in energy saving technologies. To do so, we propose different enforcement mechanisms depending not only on probability-to-audit functions but also on the situation the enforcement agency is dealing with, then we evaluate their relative performances according to incentives given for investments in R&D and emission reduction.

Both economics and law literatures on monitoring and enforcement of environmental policy have focused on the effectiveness of environmental regulations and most of the literature has examined the compliance issue based on the monitoring. Since the seminal work of Pigou (1920) it is well known among environmental economists that negative external effects such as pollution of the air and groundwater can be internalized or corrected by using an environmental tax. This first regulatory approach provides the optimal level of environmental tax (Pigouvian tax) which is determined by the marginal damage created at the optimal level of economic activity. Nevertheless, Becker (1968) pointed out that since it is costly to determine the level of damage caused by each agent, the goal should be to set up an enforcement mechanism in order to find those expenditures and punishments that minimize the total social loss. When the environmental pollution is concerned, the enforcement scheme relies on the self-reporting of agents. Kaplow and Shavell (1994) offers two advantages of this scheme : saving of enforcement resources; elimination of risk-bearing costs. As it is presented in Polinsky and Shavell (2000) the environmental enforcement literature followed from the studies on optimal penalties in law and economics, and especially the literature on mechanism design.[3] The main result of this literature is that when the enforcement agency increases monitoring efforts and

[3]For a detailed review of the literature see Cohen (1999). For the tax collection and regulation see also Border and Sobel (1987), Wagenhofer (1987) and Mookherjee and Png (1989).

inspections the compliance with the restrictions and regulations can increase. For example Becker's (1968) theory of rational crime claims that if only the expected penalty of violating exceeds the compliance cost then a profit-maximizing firm will comply with the environmental regulation. In other words, if the probability that a polluting firm gets punished is low, why would firms bother to comply ? However, in a theoretical paper Harrington (1988) showed that despite the fact that the frequency of surveillance is low and that penalties are rarely assessed even when firms are discovered to be violating, they still comply to a much higher degree than predicted by Becker's (1968) theory. Thus a major paradox emerges which is called "Harrington paradox" by Heyes and Rickman (1999). Harrington's model is based on dividing regulated firms into two groups according to their past compliance record and finally the "stick" of stricter enforcement and "carrot" for compliance combine to create stronger incentives to comply than a simple random auditing framework. Therefore, a firm may comply even when its compliance cost exceeds the expected current penalty (Friesen, 2003). Several papers in both theoretical and empirical literature discussed this non compliance issue ; some examples are Nyborg and Telle (2006), Russell (1990) and Raymond (1999).

In a relatively recent study on the issue, Macho-Stadler and Pérez-Castrillo (2006) argue that the optimal audit policy in environmental regulation requires that the resources are devoted to the easiest-to-monitor firms and to those firms that value pollution the less. Their analysis is based on a constant (random) audit probability. However, endogenizing the audit probability with respect to the emission levels or some signals about the emission levels may improve the environmental outcome.

Another widely used framework for studying behavior of a firm subject to environmental regulation is that the regulator minimizes auditing costs or maximizes social welfare controlling the audit probability. In this kind of models, taking into account its budget and the cost of an audit, the regulator decides on the probability of auditing each type of firm (a useful overview of this literature is provided in Bontems and Rotillon (2002)). However, our approach differs from such a framework in several key aspects. First of all, it is not our intention to deal with the regulator's budget or the audit costs. Second, and more important, although the aim of the regulator in our model is to maximize the social welfare by decreasing polluting emissions, this goal is addressed by choosing an enforcement mechanism rather than by deciding the probability of auditing. Since the influence of each mechanism may be different on the firm behavior, outcomes with respect to emission levels may also be different and an optimal enforcement mechanism is required for the social welfare. Consequently, mechanism design, more specifically, the form of the probability-to-audit function, is the main issue that we are concerned with in this chapter.

Even if the primary aim of the environmental regulation is to compensate for the damage created by pollutant activities, the motivation and incentives of polluters to innovate in energy efficient and cleaner technologies should also constitute an important component of the environmental enforcement mechanisms. Therefore the present study aims also to include innovation activities of firms into the environmental regulation setup. In this context, we investigate the relationship between the enforcement mechanism and R&D efforts.

The disposition of the chapter is as follows. In Section 2, we commence by briefly describing the main properties of the model and examine behavior of a firm subject to environmental regulation with regard to its emission level. We compare the perfect information case with the asymmetric information case. In the asymmetric information case we propose two different mechanisms for the enforcement agency which applies then different probability-to-audit functions. The function may be an increasing function of either the signal that receives the regulatory authority from the activity of each firm or the difference between the signal and the emission report given by the firm. To be more precise, the signal reflects the polluting characteristic or the image of the firm that the regulator observes. Each firm is classified according to this *possibility to pollute* and then this information is used to determine the audit probability. This image can be manipulated with some costly effort. For example, there is always the possibility to build a park or to donate to the city council and have a contribution in the improvement of the environmental standards in the neighborhood in order to appear as a less polluting firm. In section 3 we set up another framework for combining the R&D investment decisions with the emission decisions. This section investigates the previous behaviors when firms are allowed to invest in environmental friendly technologies. Here there will be a trade off between the costs of manipulating and the costs of research and development expenditures. The intuition suggests that as the enforcement agency becomes more efficient in regulating and auditing then firms will be more inclined to invest. In other words the efficiency of enforcement agency will be coupled. In section 4 we present the concluding remarks.

2 Emission reduction scheme

The basic model follows from Macho-Stadler and Pérez-Castrillo (2006). We consider a single competitive firm which chooses explicitly an emission level e. The firm benefits from emissions. The benefit from emissions is represented by the function $g(e)$ which satisfies with the Inada conditions following two properties : $g_e > 0$ and $g_{ee} < 0$ (subscripts on a function denote derivatives of the function throughout the chapter; for example, $g_e = \partial g(e)/\partial e$ and $g_{ee} = \partial^2 g(e)/\partial e^2$). The enforcement agency has to control the pollution and consequently, the emission levels are taxed linearly at a rate t. In our model we do not deal with the determination of this rate. On the other hand, since the enforcement agency can not perfectly monitor the damage or the emissions, we are concerned with the enforcement policy and the emission levels that will be determined accordingly. In order to do so, we have to compare two cases : perfect monitoring and imperfect monitoring.

2.1 Enforcement agency's problem

Let us assume first that the regulatory authority disposes full information about the emission level of the firm. Then, the profit function of the firm can be written as :

$$\Pi(e) = g(e) - te \tag{4.1}$$

The fist order condition (FOC) from the maximization of this equation yields to the optimal emission level e^S given by the well known equality between the marginal benefit from pollution and the cost of emission, that is :

$$g_{e^S} = t \tag{4.2}$$

Eq. (4.2) states the optimal level of emission which is decreasing in t.

Suppose now that the regulator does not know the emission level of each firm and choses an enforcement policy to achieve environmental improvements. This is a realistic assumption as it is difficult to monitor and verify emission levels. As a result, regulatory authorities apply some enforcement mechanisms and audit firms with certain probability α. However, as auditing is not costless, an optimal audit mechanism is also required. In this chapter we do not deal with inspection and enforcement costs. In the literature there exist several models proposed for tackling this issue (see for example, Friesen (2003)). Moreover, there may be no need to frame enforcement costs, if one's perspective rests on the idea that the enforcement agency's problem is to choose among different enforcement mechanisms having the same cost structure, that which leads to lower emissions is very likely to be chosen. As a result, aiming at maximizing social welfare, assumed to be the enforcement agency's objective, may be written in the following explicit form :

$$\max \; W(e)$$

where $W_e < 0$.

To achieve this objective, the enforcement agency should determine an optimal enforcement mechanism in such a way that this will induce firms to decrease their emission levels.

The enforcement agency may choose to rely on the emission report given by the firm denoted by z. Here it is important to note that the reported emission level can be different from the true level. The rationality condition requires that z is not greater than e and in fact as firms are profit maximizers, z satisfies $z \leq e$.

In addition to the reported emission level z the enforcement agency receives an emission signal f which is assumed to be correlated with e.[4] As a result the enforcement agency may follow an environmental policy such that the audit probability

[4]The idea of the use of signal, that is, choosing a probability of audit function depending on the signal received by the enforcement agency, has often been adopted in the case of income taxation. See for example Scotchmer (1997) for the issue. Also compare Jones and Scotchmer (1990).

depends on the signal. We assume that firms know the policy. We will consider two alternatives. First, the audit probability depends only on the signal f and in the second case we will assume that the difference between the signal and the reported emission determines this probability. Before we proceed, we should make some assumptions that will be used throughout the chapter.

We suppose that if a firm is discovered to have underreported taxable emission, the true level of emission can be covered. The firm that is audited and found underreporting must pay the tax on the unreported emission plus a penalty based on the difference between true and reported emission level.

Assumption 1 The penalty takes the form $\theta(u)$ where $u = e - z$ and $u \geq 0$.

Assumption 2 $\theta(0) = 0$, $\theta_u > 0$.

Assumptions 1 and 2 imply that the penalty function is increasing with respect to e and decreasing with respect to z.

Remark 4.1 *Notice that the expected tax payment of the firm should satisfy the following condition :* $tz + \alpha(.)tu + \alpha(.)\theta(u) \leq te$. *If the expected tax payment in case of underreporting exceeds the expected tax payment in case of truthful revelation there will be an incentive to truthfully report the emission level. As a result the audit probability can not exceed* $\frac{1}{\frac{\theta(u)}{tu}+1}$.

2.1.1 Audit probability as a function of the signal

The enforcement agency uses the signal to determine the probability of auditing. The reports are used for the determination of the amount of tax and the penalties.

Assumption 3 The audit probability is $\alpha(f)$.

Assumption 4 $\alpha(0) = 0$, $\alpha_f > 0$, $\alpha_{ff} > 0$.

Consider the following profit function of a representative firm that will be audited with a probability of α :

$$\Pi(e,z) = g(e) - tz - \alpha(f)tu - \alpha(f)\theta(u) \tag{4.3}$$

The optimal level of emission e^{Af} and the report z^{Af} are obtained through the maximization of the expected profit with respect to the true emission level e and the reported level z. The FOCs are as follows :

$$\begin{aligned} \frac{\partial \Pi(e,z)}{\partial e} &= g_e - \alpha_f(tu + \theta(u)) - \alpha(f)(t+\theta_u) = 0 \\ \frac{\partial \Pi(e,z)}{\partial z} &= -t + \alpha(f)(t+\theta_u) = 0 \end{aligned} \tag{4.4}$$

Result 1 $e^{Af} < e^S$ for all $z^{Af} < e^S$ and $e^{Af} = e^S$ for $z^{Af} = e^S$. Note that $\left.\frac{\partial \Pi(e,z)}{\partial e}\right|_{e=e^S} = -\alpha_f(t(e^S - z^{Af}) + \theta(e^S - z^{Af})) \leq 0.$

This result is in contradiction with the result of Macho-Stadler and Pérez-Castrillo (2006) since when there is imperfect monitoring they show that the optimal emission level may be greater under the assumption that the audit probability is exogenous. We see that altering this assumption leads to a completely different result : since the enforcement agency can choose a different audit probabilities taking into account the signal, this policy has an incentive effect on emission reduction.

Remark 4.2 *The optimal emission report is obtained through the identity :* $\alpha(f) = \frac{t}{t+\theta_u}$. *The difference between the reported and the true level should decrease as the audit probability increases (* $\lim\limits_{\alpha(f)\to 0} \theta_u = \infty$ *and* $\lim\limits_{\alpha(f)\to 1} \theta_u = 0$*). That is in accordance with the intuition.*

Proposition 1 For a given level of tax rate t and penalty function $\theta(u)$ the optimal level of emission and report decisions for the firm are $(e^{Af},\, z^{Af})$:

if $e \geq \bar{e}_2$ then $e^{Af} = e^S$ and $z^{Af} = e^{Af}$.

if $\bar{e}_1 < e < \bar{e}_2$ then $e^{Af} < e^S$ and e^{Af} satisfies Eq. (4.4) with $z^{Af} < e^{Af}$.

if $e < \bar{e}_1$ then $e^{Af} < e^S$ and e^{Af} satisfies Eq. (4.4) with $z^{Af} = 0$. $\bar{e}_2$ satisfies the condition $(1 - \alpha(f))t = \alpha(f)\theta_u(0)$ and $\bar{e}_1$ satisfies $(1 - \alpha(f))t = \alpha(f)\theta_u(\bar{e}_1)$

See Fig. 4.1 for the figure of this Proposition 1.

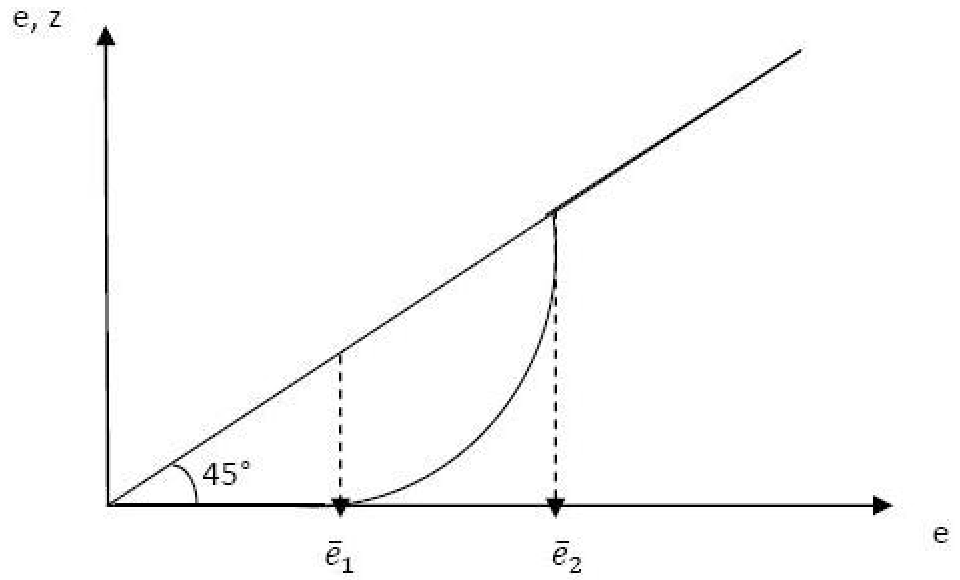

FIG. 4.1 – Firm's decision on the emission level and the report

2.1.2 Audit probability as a function of the difference between the signal and the report

In the previous section the enforcement agency uses the signal to determine the audit probability. Another approach at this point can be to use the difference between the emission signal and the emission report to determine the audit probability.

Assumption 5 The audit probability in this case given by $\alpha(v)$ where $v = f - z$.

Assumption 6 $\alpha(0) = 0$, $\alpha_v > 0$.

The profit of the firm becomes :

$$\Pi(e, z) = g(e) - tz - \alpha(v)t(e - z) - \alpha(v)\theta(u) \tag{4.5}$$

Optimal level of emission e^{Av} and the report z^{Av} easily derive from the FOCs given below.

$$\begin{aligned} \frac{\partial \Pi(e,z)}{\partial e} &= g_e - \alpha_v(tu + \theta(u)) - \alpha(v)(t + \theta_u) = 0 \\ \frac{\partial \Pi(e,z)}{\partial z} &= -t + \alpha_v(tu + \theta(u)) + \alpha(v)(t + \theta_u) = 0 \end{aligned} \tag{4.6}$$

Result 2 $e^{Av} = e^S$. Adding up the first order conditions we obtain $g_{e^{Av}} = t = e^S$

This result indicates that choosing an audit probability which is a function of the difference between e and z leads to truthful revelation of the emission level. In the next section this set-up will be further complicated by the combination of asymmetric information between the regulator and firms with the possibility of employing compliance and cheating strategies at the firm level.

2.2 Firm's behavior

Suppose now that firms have two options ; complying with the enforcement policy or cheating. Compliance has the cost of environmental tax, and cheating has *signal manipulating cost* which will be given by a function τ (these notions will be defined and explained below). As in the previous section, we first deal with the case in which only the signal is used in the probability-to-audit function. If one considers a symmetric information case this will lead to the same results given in Eqs. (4.1) and (4.2). It is more interesting to ask whether firms' behavior changes in the asymmetric information cases.

2.2.1 Audit probability as a function of the signal

The model environment can be described by the following assumptions.

Assumption 7 The probability-to-audit function is given by $\alpha(f(e,\gamma))$ where f is the signal that receives the regulatory from the activity of each firm. This term can also be described as the image perceived by the regulator which classifies each firm according to the *possibility to pollute*. The audit probability is determined taking into account this information.

Assumption 8 $f_e > 0$ and $f_\gamma < 0$.

Assumption 9 Any firm has the possibility to manipulate its image in order to appear different from its real polluting character. γ represents the effort made by the firm to do so. It may thus defined as the *cheating effort*. However, this effort is not costless. As we mentioned before, the signal manipulating cost is given by $\tau(e - f(e,\gamma)) = \tau(d)$ where $\tau_d > 0$.

The profit of the firm having the opportunity to cheat on its emission level can be written as :

$$\Pi(e,z,\gamma) = g(e) - tz - \alpha(f(e,\gamma))tu - \alpha(f(e,\gamma))\theta(u) - \tau(d) \tag{4.7}$$

If one follows Becker's (1968) theory of rational crime, the following remark should be made.

Remark 4.3 *A firm's compliance decision is made by comparing tax payment on its polluting emissions with the sum of expected penalty for emissions and the cost of cheating effort. As a result we should have the following inequality :* $tz + \alpha tu + \alpha\theta(u) + \tau(d) \leq te$. *We have thus an audit probability which has an upper bound given by* $1 - \frac{\tau(d)+\theta(u)}{tu+\theta(u)}$.

The FOCs will give us the optimal emission level which is denoted by e^{Mf} :

$$\frac{\partial \Pi(e,z,\gamma)}{\partial e} = g_e - \alpha_f f_e tu - \alpha(f(e,\gamma))t - \alpha_f f_e \theta(u) \tag{4.8}$$
$$-\alpha(f(e,\gamma))\theta_u - \tau_d(1-f_e) = 0$$
$$\frac{\partial \Pi(e,z,\gamma)}{\partial z} = -t + \alpha(f(e,\gamma))(t+\theta_u) = 0 \tag{4.9}$$
$$\frac{\partial \Pi(e,z,\gamma)}{\partial \gamma} = -\alpha_f f_\gamma(tu+\theta(u)) - \tau_d(-f_\gamma) = 0 \tag{4.10}$$

Proposition 2 When the information is asymmetric between the regulator and regulated firm, if the audit probability is a function of the signal received (manipulated or not) the optimal emission level e^{Mf} is decreased relative to that obtained in the symmetric information case e^S.

Proof. Replacing Eq. (4.2) in Eq. (4.8) and after a simple arrangement we get $\frac{\partial \Pi(e,z,\gamma)}{\partial e}|_{e=e^S} = t - \alpha_f f_e(tu+\theta(u)) - \alpha(t+\theta_u) - \tau_d(1-f_e)$. α term in this expression is replaced by its value obtained from Eq. (4.9), then Eq. (4.10) is used for replacing α_f and after some algebra one gets $\frac{\partial \Pi(e,z,\gamma)}{\partial e}|_{e=e^S} = -\tau_d < 0$, that is, $e^{Mf} < e^S$. ∎

Proposition 3 The firm's optimal emission level without cheating strategy e^{Af} is equal to that in the presence of cheating strategy e^{Mf}.

Proof. Substitute first g_e in Eq. (4.4) with its value obtained from Eq. (4.8). Use Eq. (4.10) to obtain $\alpha_f = \frac{\tau_d}{tu+\theta(u)}$ and replace it in Eq. (4.4). And since from Eq. (4.9) $\alpha(f(e,\gamma)) = \alpha(f)$, after some rearrangements the left hand side of Eq. (4.4) will be zeroed, which means that $\frac{\partial \Pi(e,z)}{\partial e}|_{e=e^{Mf}} = 0$, that is $e^{Af} = e^{Mf}$.

∎

2.2.2 Audit probability as a function of the difference between the signal and the report

We now assume that the enforcement agency considers both the signal and the report in determining the probability-to-audit function. The profit of the firm becomes :

$$\Pi(e,z,\gamma) = g(e) - tz - \alpha(f(e,\gamma)-z)tu - \alpha(f(e,\gamma)-z)\theta(u) - \tau(d) \qquad (4.11)$$

In this case, the optimal emission level denoted by e^{Mv}, can be obtained through the FOCs given below :

$$\frac{\partial\Pi(e,z,\gamma)}{\partial e} = g_e - \alpha_v f_e(tu+\theta(u)) - \alpha(v)(t+\theta_u) - \tau_d(1-f_e) = 0 \qquad (4.12)$$

$$\frac{\partial\Pi(e,z,\gamma)}{\partial z} = -t + \alpha(v)(t+\theta_u) + \alpha_v(tu+\theta(u)) = 0 \qquad (4.13)$$

$$\frac{\partial\Pi(e,z,\gamma)}{\partial \gamma} = -\alpha_v f_\gamma(tu+\theta(u)) + \tau_d(f_\gamma) = 0 \qquad (4.14)$$

from which we may prove the following proposition.

Proposition 4 When the audit probability is endogenized in a fashion that it depends on the difference between the report given by the firm and the signal received by the enforcement agency then the asymmetric information case gives an optimal emission level e^{Mv} equal to that obtained in the symmetric information case e^S.

Proof. Use Eq. (4.2) to eliminate g_e in Eq. (4.12). From Eq. (4.13) get $\alpha(v) = \frac{t-\alpha_v(tu+\theta(u))}{t+\theta_u}$ and use Eq. (4.14) to replace α_v in this equation. Then in Eq. (4.12) substituting $\alpha(v)$ and α_v by their values obtained yields after some algebra $\frac{\partial\Pi(e,z,\gamma)}{\partial e}|_{e=e^S} = 0$, which means that we have $e^{Mv} = e^S$. ■

3 Investment in R&D scheme

In the models presented above, firms benefit from emissions since the latter is used as a proxy for the level of production. However, the search for cleaner technologies are also on their agenda. The introduction of investment in R&D as a means to reduce emission levels for a given level of production and to increase the productivity requires another analytical framework. The motivation of this current model is to analyze the forces that determine, on the one hand, the rate of technological change driven by R&D investment and on the other hand the optimal level of emissions which are also affected by the technological progress.

Production is determined by the technological level A and, as in the previous model, the benefits from polluting $g(e)$. The firms conduct R&D activities to increase their productivity and to decrease the pollutant emission level. The level of R&D investment is denoted by x. The impact of the investment in R&D is twofold : x decreases the level of emissions ($e_x < 0$ and $e_{xx} > 0$) and increases the global productivity ($A_x > 0$ and $A_{xx} < 0$). Note that there is a trade-off between the technological progress and the benefit from emissions. The production function is given by the following equation :

$$Q(x) = A(x)g(e(x)) \tag{4.15}$$

Assumption 10 The marginal product of investment is nonnegative $\Delta Q(x) = A_x \Delta x + g_e \Delta e \geq 0$.

Remark 4.4 *It can be seen from Assumption 10 that the first term is positive and the second term is negative. The marginal increase in productivity should compensate for the decrease in the emission level at the new technological level.*

The technological progress is achieved through investing in R&D but this investment is costly. The cost of R&D is given by $h(x)$.

Assumption 11 There are decreasing returns to scale in R&D expenditures ($h_x > 0$ and $h_{xx} > 0$).

The remaining structural and behavioral assumptions are the same with the previous models. In what follows we compare once again two cases : symmetric information and asymmetric information.

3.1 Enforcement agency's problem

To begin, assume, first, that there is no asymmetry, thus the regulator perfectly monitors firm's emissions and the firm makes tax payments on the true emission level. The representative firm maximizes the following equation :

$$\Pi(x) = A(x)g(e(x)) - te(x) - h(x) \tag{4.16}$$

The optimal level of emission is obtained through the maximization of the profit with respect to the R&D investment level and satisfies the following identity :

$$\frac{\partial \Pi(x,z)}{\partial x} = A_x g(e(x)) + A(x)g_e e_x - te_x - h_x = 0 \tag{4.17}$$

Rearranging Eq. (4.17) yields the optimal level of investment x^S :

$$A_{x^S} g(e(x^S)) + A(x^S)g_{e(x^S)}e_{x^S} + te_{x^S} = h_{x^S} \tag{4.18}$$

Eq. (4.18) states that the marginal benefit of investing is equal to its marginal cost.

We may now proceed to the asymmetric information cases in order to analyze the differences in the firm behavior about R&D expenditures in two contexts that we introduced in the emission reduction scheme : in the first, the audit probability depends only on the signal f ; in the second, the probability becomes a function of the difference between f and z.

On the other hand the enforcement agency's objective remains the same (maximizing social welfare), except that from now on, the emission level is a function of the investment in R&D. As a result the objective becomes :

$$\max \ W(e(x))$$

where $W_x = W_e e_x > 0$.

3.1.1 Audit probability as a function of the signal

Consider a representative firm that maximizes the following equation :

$$\Pi(x,z) = A(x)g(e(x)) - tz - \alpha(f)t(e(x)-z) - \alpha(f)\theta(u) - h(x) \tag{4.19}$$

The FOCs for the equation (4.19) give the following identities :

$$\begin{aligned} \frac{\partial \Pi(x,z)}{\partial x} &= A_x g(e(x)) + A(x) g_e e_x \\ &\quad -\alpha_f e_x(tu + \theta(u)) - \alpha(f)(te_x + \theta_u e_x) - h_x = 0 \\ \frac{\partial \Pi(x,z)}{\partial z} &= -t + \alpha(f)(t+\theta_u) = 0 \end{aligned} \tag{4.20}$$

Result 3 $x^{Af} > x^S$ and $x^{Af} = x^S$ for $z^{Af} = e(x^S)$. Note that $\left.\frac{\partial \Pi(x,z)}{\partial x}\right|_{x=x^S} = -\alpha_f e_x(t(e(x^S) - z^{Af}) + \theta(e(x^S) - z^{Af})) \geq 0$.

This result clearly shows that in the asymmetric information case when the enforcement agency choses an audit function depending on the signal, R&D activities are greater than that of symmetric information case.

3.1.2 Audit probability as a function of the difference between the signal and the report

The profit function that the representative firm maximizes in this case can be written as :

$$\Pi(x,z) = A(x)g(e(x)) - tz - \alpha(v)t(e(x)-z) - \alpha(v)\theta(u) - h(x) \tag{4.21}$$

The optimal level of R&D and report are obtained through the maximization of the profit with respect to the R&D investment level and the emission report. The FOCs are as follows :

$$\begin{aligned} \frac{\partial \Pi(x,z)}{\partial x} &= A_x g(e(x)) + A(x) g_e e_x \\ &\quad -\alpha_v e_x (tu + \theta(u)) - \alpha(v)(te_x + \theta_u e_x) - h_x = 0 \\ \frac{\partial \Pi(x,z)}{\partial z} &= -t + \alpha_v (tu + \theta(u)) + \alpha(v)(t + \theta_u) = 0 \end{aligned} \tag{4.22}$$

Then we can write the following result.

Result 4 $x^{Av} = x^S$. Adding up the first order conditions we obtain $A_x g(e(x)) + A(x) g_{e(x)} e_x + te_x = h_x$.

In this case the amount of R&D is equal to that of perfect monitoring case which means that we are in the presence of truthful revelation.

3.2 Firm's behavior

Suppose once again that a firm may cheat on its emissions when the occasion arises. We move directly to the asymmetric information case as in the symmetric information case the results from enforcement agency's problem hold.

3.2.1 Audit probability as a function of the signal

We can write the profit function of the firm in the following fashion :

$$\Pi(x, z, \gamma) = A(x)g(e(x)) - tz - \alpha(f(e(x), \gamma))tu - \alpha(f(e(x), \gamma))\theta(u) - \tau(d) - h(x) \tag{4.23}$$

The profit-maximizing level of investment in R&D (x^{Mf}), report level and cheating effort can be derived from the FOCs given below :

$$\begin{aligned}
\frac{\partial \Pi(x, z, \gamma)}{\partial x} &= A_x g(e(x)) + g_e e_x A(x) - \alpha_f f_e e_x (tu + \theta(u)) && (4.24)\\
&\quad -\alpha(f(e(x), \gamma))(te_x + \theta_u e_x)\\
&\quad -\tau_d(e_x - f_e e_x) - h_x = 0\\
\frac{\partial \Pi(x, z, \gamma)}{\partial z} &= -t + \alpha(f(e(x), \gamma))(t + \theta_u) = 0 && (4.25)\\
\frac{\partial \Pi(x, z, \gamma)}{\partial \gamma} &= -\alpha_f f_\gamma (tu + \theta(u)) - \tau_d(-f_\gamma) = 0 && (4.26)
\end{aligned}$$

Proposition 5 If the regulatory authority endogenizes the audit probability using an audit function $\alpha(f(e(x), \gamma))$ then it is optimal for the firms to invest in clean energy technologies more than the investment levels in symmetric information case x^S.

Proof. Replace first h_x in Eq. (4.24) with its value given in Eq. (4.18). Then, use Eq. (4.25) and Eq. (4.26) to replace respectively $\alpha(f(e(x), \gamma))$ and α_f in Eq. (4.24). After these substitutions and some arrangements we have *in fine* $\frac{\partial \Pi(x,z,\gamma)}{\partial x}|_{x=x^S} = -\tau_d e_x > 0$, that is, $x^{Mf} > x^S$, where x^{Mf} is the optimal level of R&D. ■

Proposition 6 The firm's optimal R&D level without cheating strategy x^{Af} is equal to that in the presence of cheating strategy x^{Mf}.

Proof. Use Eq. (4.24) to substitute h_x in Eq. (4.20). From Eq. (4.26) get $\alpha_f = \frac{\tau_d}{tu+\theta(u)}$ and use it in Eq. (4.20). From Eq. (4.25) it follows that $\alpha(f(e,\gamma)) = \alpha(f)$. After some algebra, one finds easily that the left hand side of Eq. (4.20) is zero meaning that $\frac{\partial \Pi(x,z,\gamma)}{\partial x}|_{x=x^{Mf}} = 0$, that is $x^{Af} = x^{Mf}$. ■

3.2.2 Audit probability as a function of the difference between the signal and the report

We can write the profit function of the firm in the following fashion :

$$\Pi(x,z,\gamma) = A(x)g(e(x)) - tz - \alpha(f(e(x),\gamma)-z)tu - \alpha(f(e(x),\gamma)-z)\theta(u) - \tau(d) - h(x) \tag{4.27}$$

From the FOCs cited below we obtain the profit-maximizing level of investment in R&D (x^{Mv}), emission report level and cheating effort.

$$\begin{aligned} \frac{\partial \Pi(x,z,\gamma)}{\partial x} &= A_x g(e(x)) + g_e e_x A(x) - \alpha_v f_e e_x (tu+\theta(u)) \qquad (4.28)\\ &\quad -\alpha(v)(te_x + \theta_u e_x) - \tau_d(e_x - f_e e_x) - h_x = 0 \\ \frac{\partial \Pi(x,z,\gamma)}{\partial z} &= -t + \alpha(v)(t+\theta_u) + \alpha_v(tu+\theta(u)) = 0 \qquad (4.29)\\ \frac{\partial \Pi(x,z,\gamma)}{\partial \gamma} &= -\alpha_v f_\gamma (tu+\theta(u)) + \tau_d(f_\gamma) = 0 \qquad (4.30) \end{aligned}$$

Proposition 7 If the regulatory authority endogenizes the audit probability then it is optimal for the firms to invest in clean energy technologies more than the investment levels in perfect monitoring case x^S if only $t \leq \tau_d$.

Proof. First use Eq. (4.18) to replace h_x in Eq. (4.28). Then following the same procedure as above in the proof of Proposition one can easily get the following condition : $\frac{\partial \Pi(x,z,\gamma)}{\partial x}|_{x=x^S} = (e_x - 1)(t - \tau_d) \geq 0$ if $t \leq \tau_d$.■

This proposition implies that there exists an upper bound for the environmental tax level exceeding which may create a disincentive to undertake R&D activities. This result may be viewed in another way : if the marginal cost of signal manipulating effort is lower than the tax rate the firm may choose to cheat by decreasing its abatement effort and not to comply with the environmental regulation.

4 Conclusion and discussion

In this chapter we have considered an environmental tax per emission and have provided two different cases : symmetric and asymmetric information. In the asymmetric information case the possibility of compliance and cheating strategies at the firm level is also accounted for. Table 4.1 summarizes firms' reactions to different audit strategies.

Tab. 4.1 – Firm responses to regulator's audit strategies

	Symmetric information	Asymmetric information			
		$\alpha(f)$	$\alpha(f-z)$	$\alpha(f(e,\gamma))$	$\alpha(f(e,\gamma)-z)$
Emission	e^S	$e^{Af} < e^S$	$e^{Av} = e^S$	$e^{Mf} < e^S$	$e^{Mv} = e^S$
levels		$e^{Af} = e^{En}$		$e^{Mf} = e^{Af}$	
R&D	x^S	$x^{Af} > x^S$	$x^{Av} = x^S$	$x^{Mf} > x^S$	$x^{Mv} \geq x^S*$
efforts		$x^{Af} = x^{Mf}$		$x^{Mf} = x^{Af}$	

* for $t \leq \tau_d$

We find out that if the probability-to-audit function is an increasing function of the signal received, whether manipulated or not, the emissions are reduced with respect to those in the perfect monitoring case. Furthermore, incentives for the adoption of cleaner technologies are also analyzed within the same framework of this study. The resulting conclusion is that firms may increase their efforts to comply with the environmental regulations if the regulatory authority applies an appropriate enforcement mechanism instead of a random auditing policy. We show that again an audit mechanism using only emission signal instead of the gap between the emission signal and report may lead to better results. Furthermore we detect a threshold level for the environmental tax given by the marginal cost of cheating, which should not be exceeded if the regulatory authority wishes to increase R&D efforts at the firm level.

In closing this chapter, it is worthwhile to give a brief overview of the environmental tax system in Turkey. Revenues raised from environmentally related taxes in 1994, 2000 and 2005 are respectively, 1916.6, 6347.1 and 19929.1 millions US $. This pattern indicates a very fast increase in such revenues, namely 939% from 1994 to 2005.[5] Another ratio to consider is that total tax revenue raised through environmentally related taxes represents 1.7% of GDP in 1995 while it reaches 5.2% in 2003. Moreover, the share of revenues from the environmental tax system represents less than 7% of total tax revenue in 1995 and it corresponds to 16% in 2003. This corresponds to 130% of increase for a period of 8 years, which makes Turkey, by far, the country which has the highest share of total environmental tax revenue among other OECD countries (OECD, 2006). On the other hand, emission levels per total primary energy supply (TPES) do not decrease but increase slightly (see Figs. 1

[5]This fast growth in the revenues raised from environmentally related taxes is due to (1) special consumption tax on fuels and (2) special consumption tax on motor vehicles. For more information, the reader is encouraged to consult the excellent database on environmentally related taxes, fees and charges, other economic instruments and voluntary approaches used in environmental policy and natural resources management provided by European Environment Agency and OECD, which is available online at http ://www2.oecd.org/ecoinst/queries/index.htm.

and 2 in the introductionary chapter of this document). In such a case, one may say that the Turkish environmental regulation system even tough collects a considerable amount of taxes, it does not motivate for any innovative activities to reduce pollutant emissions. Furthermore, the reason behind this can be easily understood by considering the taxation scheme : municipalities collect an environmental tax in order to finace certain services like garbage collection. However, this environmental taxation occurs in the form of a lump-sum tax to be paid by every firm regardless of its emission level and the amount of this tax varies only according to the location of the firm.

As a result, the main policy implication which may be drawn from these study findings is that in Turkey, correction of the environmental regulation framework would require the application of environmental tax per emission first and then an appropriate choice of enforcement mechanism for incentives for reducing emissions and for R&D.

The following chapter proposes a new framework and point of view for the study of the effects of environmental regulation on the firm behavior. It considers explicitly the problem of unrecorded economy, showing that the regulatory authority's problem is twofold : (1) asymmetric information about the emission levels and (2) income tax evasion. As such, it will no doubt accomplish our purpose in this thesis.

Chapitre 5

Environmental regulation in the presence of unrecorded economy

1 Introduction and relation to previous literature

To what extend does the economic theory of environmental regulation explain the unfolding of firms' behavior and would it be adequate to apply it on an "as-is" basis to both developed and developing countries ? In order to provide a sufficiently well-developed response to this question one should take into account the weight of unrecorded activities in the overall economy, particularly in developing countries. Since in these countries the size of unrecorded economy is estimated to be very large (see Table 5.1) the overall impact of environmental regulation should be re-examined both theoretically and empirically. Hence, our primary interest in the problem studied here arose from the fact that the results from the existing literature may not be reliable ; thus, for the case for most of the developing countries, attempts to give recommendations and policy implications following previous studies on environmental regulation may not go further than being inadequate and even misleading.

Several papers investigate only unrecorded economy, its causes and consequences : unemployment, increased regulation in the recorded economy, corruption, rise of the tax burden are the most cited causes of unrecorded economy while existence of a Laffer curve[1], reduced effectiveness of macroeconomic policies, economic instability, distortions in resource allocations and underinvestment represent its main conse-

[1]This inverted U shaped curve shows that governments may increase their tax revenues by increasing the tax rate up to an *optimal* tax rate beyond which further increase of taxation decreases tax revenues. In the presence of an unrecorded economy the tax base is smaller than it should be without unrecorded economy. Increasing taxes to compensate the revenue loss resulting from unrecorded activities drives firms out of the official economy, thus increasing further the size of unrecorded economy. This vicious circle characterizes at the same time cause and consequence of the unrecorded economy.

quences (Schneider and Enste, 2000 ; Eilat and Zinnas, 2002).[2] In these studies, special attention is given, on the one hand, to the methodological issues in the estimation of the size of unrecorded economy and on the other hand, to the overall macro- and micro-economic impacts of unrecorded activities without providing necessary and useful implications for the environmental policy more specifically for the possible relationship between environmental regulation and the size of unrecorded economy.

Tab. 5.1 – The average size of the unrecorded economy in developed and less developed countries

Countries/Continents		Size as % of GNP
Developed	OECD countries	12
Transition	Former Soviet Union	25
	Middle and Eastern Europe	20
Developing	Africa	44
	Latin America	39
	Asia	35

Source : Gerxhani (2004 : 268, Table 1).

Other studies concentrate only on the environmental regulation and enforcement

[2]One of the most used definitions of unrecorded economy is from Smith (1994, p.18) who defines it as "market-based production of legal goods and services that escapes detection in the official estimates of GDP due to the efforts of some businesses and households to keep their activities undetected". To conserve space, we do not discuss in detail definition and theoretical and empirical foundations of the estimation of unrecorded economy which are well documented in the literature. For a good overview of these and other issues discussed in this paragraph see for example Feige (1990) and also Karanfil and Ozkaya (2007).

policy without examining whether there exists an unrecorded economy. Since the pioneering study of Pigou (1920) it has been recognized that a regulatory authority can internalize external costs resulting from production (emissions) by introducing an environmental tax determined by the marginal damage created from this activity (i.e. Pigouvian tax). Obviously, the world is not as simple as Pigou's (1920) basic economic model. The main problem in this area is that it is not easy or cheap to identify the emission level of each firm, therefore an efficient enforcement mechanism is needed in order to minimize the total social loss (Becker, 1968). Following this, more recent studies addressed monitoring and optimal enforcement mechanism design issues and reported several interesting findings (see Cohen (1999) and Lewis (1996) for a survey). In the same line of research, for example, in an oligopolistic competition framework, Damania (2000) points out that a high emission tax rate may not be effective in decreasing total emissions and in some circumstances it may even increase them. On the other hand, Macho-Stadler and Pérez-Castrillo (2006) argue that in order to decrease total emissions the most suitable strategy that can be adopted by the environmental enforcement agency is a "discriminatory" audit strategy which consists of focusing on both the "easier-to-detect" firms and firms that value pollution less. Furthermore, some very recent studies on the relationship between enforcement mechanism and firm's compliance behavior demonstrated that in a market involving widespread non-compliant firms environmental quality (lower emissions) is positively associated with managers' risk aversion (Stranlund, 2008) and that an increase in enforcement efforts may provide better environmental results inducing not only non-compliant firms to comply with the regulation but also *over*-compliant firms to reduce further their emissions (Shimshack and Ward, 2008).

None of the aforementioned studies has assessed whether taking into account unrecorded economy leads to a substantial change in the conclusions reached. To date, the only study available addressing the issue of variability of the results obtained in an energy-environment-income nexus once unrecorded activities are accounted for is that of Karanfil (2008) who concluded that for the case of Turkey there exists a long-run causality from *official* GDP to energy consumption while *true* GDP and energy consumption are found to be neutral with respect to each other and that as a results, adjustment policies and structural reforms aiming at decreasing the size of unrecorded economy may not serve as a complement to environmental policies which may be feasible without harming *recorded* economic growth.

In consequence of the above mentioned facts, for developing countries, the analysis conducted in this chapter is much more appropriate than earlier papers in this field in at least two ways : first it considers an economy composed of both recorded and unrecorded activities ; second, the impacts of an environmental enforcement policy on the size of unrecorded economy are analyzed, which, to the best of our knowledge, has not done before.

The outline of the chapter is the following : In Section 2, the model environment is described and the assumptions on which the model is based are discussed. In Section 3, behaviors of firms subject to non-cooperative fiscal and environmental regulations are analyzed and after determining reaction functions which give the firms' Cournot equilibrium quantities, some stability and comparative static analysis are conducted. Moreover, the results from Cournot game are compared to those obtained in Stackelberg market. Proposing another enforcement mechanism where firms are audited on their productions and emissions with a unique probability which is supposed to be a function of the reported production, Section 4 establishes a threshold rate of environmental tax which, if it is exceeded, may lead to an increase of the size of unrecorded economy. To provide further information, a similar Stackelberg framework is used as in Section 3. The final section concludes the chapter and discusses in brief detail the implications of the findings.

2 Model environment

We model an industry where there are both recorded and unrecorded economic activities. We deal with two representative duopolistically competitive firms. Existence of duopolistic competition in the presence of unrecorded economy may be perceived in the following way : In an industry we may have a large number of differentiated goods and in the production of some homogeneous goods there may be a duopolistic competition. Thus the industry would be composed of a large number of duopolistically competitive firms for every of these homogeneous goods. In this situation the regulatory authorities can perfectly observe neither the production nor the emission level of each firm. As a result, they use auditing mechanisms to create incentives for truthful revelation.

Each firm faces a linear market demand for its homogeneous product ; q^R and q^U (Superscripts on a variable or on a parameter denote activity characteristic of the firm throughout the chapter ; R stands for recorded economy and U for unrecorded economy). The homogeneity assumption is not unrealistic since unrecorded economy is generated by mainly tax evasion in economic activities like peddling or hawking where the product differentiation is not very great (Karanfil, 2008).

On the other hand, let the linear inverse market demand function be $p(Q) = a - bQ$ where $p(Q)$ and b stand for market price and the slope of the demand function respectively. Q is the aggregate output, that is, $Q = q^R + q^U$.

To make ideas more concrete and to have simpler and analytically more tractable model we shall also make the following assumptions. As the constraints faced by firms in the presence of unrecorded economy are asymmetric, an asymmetric cost function should be used for each firm. Consider the following cost function of a representative firm reporting all its activity (henceforth firm R) : $c^R(q^R, x^R) = \varphi^R \frac{1}{2} q^{R^2} + \phi^R \frac{1}{2} x^{R^2}$. Marginal cost of production and marginal cost of pollution abatement effort x^R are determined by the production efficiency φ^R and the abatement efficiency ϕ^R respectively. The polluting emission level of the firm R, e^R, is given by a linear function of q^R and x^R. More formally, let the emission coefficient be denoted by δ^R, we have $e^R = \delta^R q^R - x^R$.

The other representative firm producing in the unrecorded economy (henceforth firm U) neither reports any of its income and its polluting emissions nor performs abatement. Thus the cost function for the firm U reduces to $c^U(q^U) = \varphi^U \frac{1}{2} q^{U^2}$ and its emission level is defined simply by $e^U = \delta^U q^U$.

Once we have described our specification of the firms' behaviors in both recorded and unrecorded economic activities, the crucial feature is how strategies are affected by both environmental and income tax enforcement policies. The next sections will address this question considering different cases with respect to the existence or non-existence of *environmental-fiscal enforcement cooperation.*

3 Non-cooperative policy

In the first framework we develop a model in which there is no cooperation between environmental and finance regulatory authorities. It means that the economic (more specifically fiscal and finance) policies to combat unrecorded economy and the environmental policies to decrease pollutant emissions are not coordinated. Hence, the information which can be used to design an enforcement policy is not common to all the enforcement agencies. As a result, firms' emission levels and productions are audited with different exogenous probabilities. The next section then introduces another enforcement policy mechanism in a cooperative policy scheme.

In the recorded economy, where there is no tax evasion, the firm R decides how much to produce, to give report on the emissions and to invest in abatement technologies solving the following maximization problem :[3]

$$\begin{aligned} Max\Pi^R &= [p(q^R + q^U) - t_Y]q^R - c^R(q^R, x^R) - t_E z \\ &\quad -\alpha_R[t_E(e^R(q^R, x^R) - z) + \theta(e^R(q^R, x^R) - z)] \end{aligned} \tag{5.1}$$

Let subscripts on a function denote its partial derivatives with respect to the indicated argument; for example, $\theta_d = \partial\theta(d)/\partial d$ and $\theta_{dd} = \partial^2\theta(d)/\partial d^2$ where $d = e^R(q^R, x^R) - z$. Then, within the specifications of the model environment, the first order conditions (FOCs) can be written as :

$$\frac{\partial \Pi^R}{\partial q^R} = -2bq^R + a - bq^U - t_Y - \varphi^R q^R - \alpha_R[(t_E + \theta_d)\delta^R] = 0 \tag{5.2}$$

$$\frac{\partial \Pi^R}{\partial x^R} = -\phi x^R + \alpha_R(t_E + \theta_d) = 0 \tag{5.3}$$

$$\frac{\partial \Pi^R}{\partial z} = -t_E + \alpha_R(t_E + \theta_d) = 0 \tag{5.4}$$

And a little algebra leads to :

$$q^R = \frac{a - bq^U - t_Y - \alpha_R[(t_E + \theta_d)\delta^R]}{2b + \varphi^R} \tag{5.5}$$

[3]For simplicity it is assumed that the firm R does not evade income tax and the firm U does not give any tax on its income. It is evident that the firm R may also under report its income, but we do not intend to tackle this specific case.

$$x^R = \frac{\alpha_R(t_E + \theta_d)}{\phi} \tag{5.6}$$

$$t_E = \frac{\alpha_R \theta_d}{1 - \alpha_R} \tag{5.7}$$

On the other hand, since the firm U has only one control variable, q^U, the maximization problem that it would face can be written as follows :

$$\begin{aligned} Max\Pi^U &= p(q^R + q^U)q^U - c^U(q^U) - \alpha_U[t_E e^U(q^U) + \theta(e^U(q^U))] \\ &\quad -\beta[t_Y q^U + \psi(q^U)] \end{aligned} \tag{5.8}$$

Next we derive the FOC with respect to q^U :

$$\frac{\partial \Pi^R}{\partial q^U} = -2bq^U + a - bq^R - \varphi^U q^U - \alpha_U[(t_E + \theta_{q^U})\delta^U] - \beta(t_Y + \psi_{q^U}) = 0 \tag{5.9}$$

which gives finally

$$q^U = \frac{a - bq^R - \alpha_U[(t_E + \theta_{q^U})\delta^U] - \beta(t_Y + \psi_{q^U})}{2b + \varphi^U} \tag{5.10}$$

In the above equations t_Y denotes unit tax on the good produced in the industry and t_E is the emission tax. Furthermore an enforcement agency (i.e. Ministry of Environment or environmental protection agency (EPA) as it is called in most of the literature) sets the audit probability α_R (α_U) which is the probability that a firm is discovered underreporting (unreporting) its emission level. If the firm R (the firm U) is caught to have underreported (unreported) emission it has to pay not only the tax on the unreported emission but also a penalty given by the function θ. We assume that this penalty function has the following properties : $\theta(0) = 0$, $\theta_d > 0$ and $\theta_{dd} > 0$. Similarly β denotes the audit probability that another regulatory authority (i.e. Ministry of Finance) determines aiming at limiting the tax evasion. In other words, with the probability of β, the firm U would be discovered having unreported taxable income and pay the tax and the penalty on its income. Again we assume that the penalty takes the form $\psi(q^U)$ with $\psi_{q^U} > 0$. Note that also we have naturally $\alpha_U, \alpha_R, \beta \in [0, 1]$.

Solving simultaneously Eqs. (5.2) and (5.9) yields the following proposition which establishes the optimal behavior of the firms R and U which can also be defined as the conditions that the Cournot-Nash equilibrium (henceforth CNE) satisfies.[4]

Proposition 1 For given audit probabilities α_R, α_U and β, tax rates t_Y and t_E, penalty functions, θ and ψ, the optimal production decisions (q^{R*}, q^{U*}) for the firms R and U with parameters (δ^R, φ^R and δ^U, φ^U) are

$$q^{R*} = \frac{[a - t_Y - \alpha_R((t_E + \theta_d)\delta^R)](2b + \varphi^U) + b[-a + \alpha_U((t_E + \theta_{q^U})\delta^U) + \beta(t_Y + \psi_{q^U})]}{(2b + \varphi^U)(2b + \varphi^R) - b^2} \quad (5.11)$$

$$q^{U*} = \frac{[a - \alpha_U((t_E + \theta_{q^U})\delta^U) - \beta(t_Y + \psi_{q^U})](2b + \varphi^R) + b[-a + \alpha_R((t_E + \theta_d)\delta^R) + t_Y]}{(2b + \varphi^U)(2b + \varphi^R) - b^2} \quad (5.12)$$

■

While after some tedious but simple algebra, using Eqs. (5.11) and (5.12) we can calculate Π^{R*}, Π^{U*} and p^*. However, to conserve space, we do not provide further details on such analysis as the main focus of the chapter is to examine the effect of environmental regulation on both recorded and unrecorded economic activities.

Eqs. (5.5) and (5.10) are called best-response functions which are illustrated in Fig. 5.1.

The intersection points of best-response functions and q^R and q^U axis given in Fig. 5.1, A, B, C and D have parametric values of $\frac{a - t_Y - \alpha_R[(t_E+\theta_d)\delta^R]}{b}$, $\frac{a - \alpha_U[(t_E+\theta_{q^U})\delta^U] - \beta(t_Y+\psi_{q^U})}{2b+\varphi^U}$, $\frac{a - t_Y - \alpha_R[(t_E+\theta_d)\delta^R]}{2b+\varphi^R}$ and $\frac{a - \alpha_U[(t_E+\theta_{q^U})\delta^U] - \beta(t_Y+\psi_{q^U})}{b}$ respectively.

[4] For a comprehensive overview of the history of game theory, with a particular focus on the CNE see Myerson (1999).

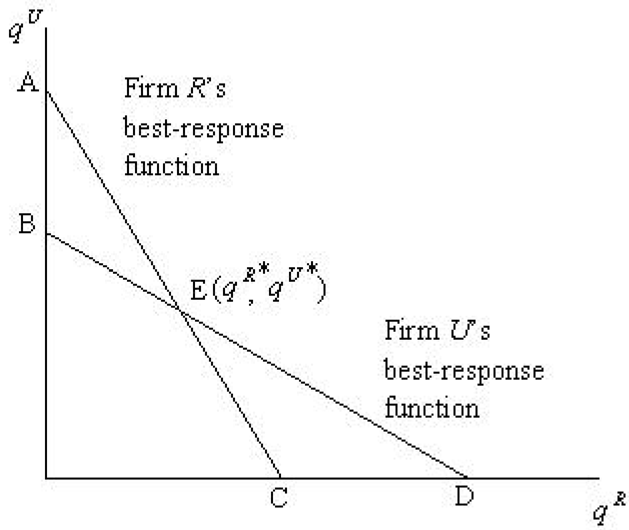

FIG. 5.1 – Firms' best-response functions

Now, we shall give the following lemma requiring in the proof of some propositions made in the remaining of the chapter.

Lemma 1 As there is no information sharing between environmental and finance regulatory authorities, the environmental regulation is conducted using an enforcement mechanism which utilizes an exogenous audit probability for all types of firms whether they have recorded or unrecorded economic activities. This means that there is no reason to have $\alpha_U \neq \alpha_R$.

Proposition 2 If one supposes that the firm R and the firm U have symmetric cost functions, that is, $\varphi^R = \varphi^U$, then the stability condition of the CNE given in Eqs. (5.11) and (5.12) requires that $\psi_{q^U q^U} > 0$.

Proof. We may give the intuition behind the proof of this proposition as follows. Even though the CNE results from a static game, if one considers a dynamic game where, in each period, the firm R (the firm U) determines its production level taking into account the production level of the firm U (the firm R) in the previous period, in order to converge step by step to the intersection point ($E(q^{R*}, q^{U*})$) given in Fig. 5.1, the slope of the best-response function of the firm R should be higher than that of the firm U. Hence, the following inequality should hold :

$$\frac{-b - \alpha_U {\delta^U}^2 \theta_{dd} - \beta \psi_{q^U q^U}}{2b + \varphi^U} < \frac{-b - \alpha_R {\delta^U}^2 \theta_{dd}}{2b + \varphi^R} \tag{5.13}$$

from which, applying Lemma 1 for $\alpha_U = \alpha_R$, we can see that the penalty function which is assumed to be increasing function of q^U should also be convex. More formally, that is, we have $\psi_{q^U q^U} > 0$. ■

We close this section by a further observation on the variations of q^{R*} and q^{U*} resulting from a change in the model parameters. The next propositions consider the effects of both environmental tax and audit probability on the size of unrecorded economy.

Lemma 2 In an economy the size of unrecorded economy can be defined and measured simply by $\frac{q^U}{q^R + q^U}$. Thus, using Eqs. (5.11) and (5.12) the size of unrecorded economy at the CNE can be calculated analytically from the equation below :

$$\frac{q^{U*}}{q^{R*} + q^{U*}} = \frac{X(2b + \varphi^R) + bY}{X(b + \varphi^R) - (b + \varphi^U)Y} \tag{5.14}$$

where $X = a - \alpha_U((t_E + \theta_{q^U})\delta^U) - \beta(t_Y + \psi_{q^U})$ and $Y = -a + \alpha_R((t_E + \theta_d)\delta^R) + t_Y$

Proposition 3 Suppose a rise in the environmental tax rate, then a sufficient condition for an increase of the size of unrecorded economy is given by : $\frac{\delta^R}{\delta^U} \geq \frac{2b + \varphi^R}{b}$

Proof. From Eq. (5.14) it can be seen that $X_{t_E} < 0$ and $Y_{t_E} > 0$. Thus the variation of the denominator is negative if the environmental enforcement agency increases the tax rate t_E. In this case, if the nominator does not decrease, the size of unrecorded economy will *a fortiori* increase. This yields after some algebra and rearrangements $b\alpha_R\delta^R \geq \alpha_R(2b+\varphi^R)\delta^U$. It also follows from our Lemma 1 : $\frac{\delta^R}{\delta^U} \geq \frac{2b+\varphi^R}{b}$.[5] ■

Before we deal with the policy issues, let us make it clear that this result implies that if the production of the firm R is environmentally less efficient with respect to that of the firm U, that is, higher emission coefficient ($\delta^R > \delta^U$) and if the regulatory authority decides to decrease the emissions by increasing environmental tax, this will have as a consequence a larger extent of the unrecorded economy. Meanwhile, we may also establish the following proposition.

Proposition 4 The optimal audit probability for the pollutant emissions is $\alpha_R = 1 - \frac{\theta_d}{\phi x^R}$.

Proof. Fist, use Eq. (5.6) to write $\alpha_R = \frac{\phi x^R}{t_E+\theta_d}$. Then substitute t_E by its value given in Eq. (5.7). Finally after some elementary manipulations get : $\alpha_R = 1 - \frac{\theta_d}{\phi x^R}$ ■

Corollary 1 An increase in the audit probability may have an adverse effect on the recorded economic activities.

Proof Following the same procedure given in the proof of Proposition 3 and again by using Lemma 1, one can prove that an increase in α_R may increase the size of unrecorded economy if the following sufficient condition is satisfied : $t_E = \frac{\theta_d b\delta^R + \theta_{qU}\delta^U(2b+\varphi^R)}{b\delta^R - \delta^U(2b+\varphi^R)}$. ■

Combining Proposition 3 with the foregoing results appears to provide a theoretical

[5]Although this result with Proposition 2 is theoretically of some interest, it seems very unlikely that it is consistent with the problem studied here. The intuition behind this is that in the context of a dynamic game each firm should observe perfectly reaction of its rival (namely the production level). However, by definition, the production level of the firm U cannot be observed directly.

ground for the very recent study of Karanfil (2008) who cites "if environmental taxes are used without reducing the overall economic costs associated with the tax system, no double dividend occurs, hence the shift in tax burden, which is certainly the driving source behind the unrecorded economy, may increase the size of unrecorded economy". As a matter of fact, in what follows, we want to go further than this proposition and provide a threshold rate of environmental tax, exceeding which may lead to an increase of the size of unrecorded economy. Before we deal with this issue, for an extension of this model we introduce a quantity competition game à la Stackelberg, where the firm R is the leader and the firm U the follower. If this assumption seems unwarranted, it is, though not *ad absurdum* since in developing countries counterfeit production represents an important part of the unrecorded economy.[6]

Proposition 5 In the Stackelberg equilibrium if only $\frac{\delta^R}{\delta^U} \geq \frac{b}{2b+\varphi^U}$, then an increase in the environmental tax impedes recorded economic activities.

Proof. See the non-cooperative policy game in Appendix A.1. ■

If one compares this result with that derived from Proposition 3, one observes that $\frac{2b+\varphi^R}{b} > \frac{b}{2b+\varphi^U}$. This means simply that the minimum value of the relative environmental efficiency ratio $\frac{\delta^R}{\delta^U}$ to have a rise in the extent of unrecorded economy after a shift in the environmental tax rate at the CNE is greater than that in the Stackelberg game to have a negative impact of an increase in environmental tax on the recorded activities.

The purpose of the next section is, in addition to an assessment of the effects of a rise in environmental tax on the extent of unrecorded economic activities, to re-

[6]Neylor (1996) provides a nice perspective on the evolution of the *modern* underground economy in which flourish activities like smuggling and counterfeiting.

examine firms' behaviors subject to a coordinated audit policy between environmental and fiscal authorities who determine endogenously a unique probability-to-audit function.

4 Cooperative policy

In this section we consider a remarkably different enforcement mechanism design which can be outlined as the following : (1) The information is symmetric between the environmental and fiscal enforcement authorities. This assumption can also be interpreted as if there exists only one enforcement agency which audits firms on their both emissions and productions. As a result, if a firm caught to be underreporting its production, *at the same time*, it can also be discovered underreporting its emissions. (2) The audit probability is no more exogenous. The environmental and fiscal enforcement authorities (or the *general* regulator) determine(s) a probability-to-audit function ($\mu(.)$) based on the information available from the recorded economic activities, which are q^R and z. We suppose that only the reported production is used for this purpose, that is, we have $\mu(q^R)$. (3) The form of the probability-to-audit function, whether increasing or decreasing with respect to q^R may be a feature of importance in the enforcement mechanism design. Therefore, some time series analysis have been performed in order to estimate the relationship between q^R and the size of unrecorded economy. The intuition behind our approach is that if, for instance, the size of unrecorded economy increases in a period of *recorded* economic growth, then having this information, regulatory authorities may increase the audit frequency on both income and emission declarations, that is higher $\mu(q^R)$. We present our data, methodology, and the empirical results in Appendix B. The tests carried out in

Appendix B show clearly that the *general* regulator's probability-to-audit function *should* be an increasing function of q^R. More formally we have $\mu_{q^R} > 0$.

In this cooperative policy case the maximization problems faced by each firm (firm R and firm U) are transformed from Eqs. (5.1) and (5.8) to the following Eqs. (5.15) and (5.16) respectively.

$$\begin{aligned} Max\Pi^R &= [p(q^R + q^U) - t_Y]q^R - c^R(q^R, x^R) - t_E z \\ &\quad -\mu(q^R)[t_E(e^R(q^R, x^R) - z) + \theta(e^R(q^R, x^R) - z)] \end{aligned} \tag{5.15}$$

$$\begin{aligned} Max\Pi^U &= p(q^R + q^U)q^U - c^U(q^U) - \mu(q^R)[t_E e^U(q^U) + \theta(e^U(q^U)) \\ &\quad +t_Y q^U + \psi(q^U)] \end{aligned} \tag{5.16}$$

Proposition 6 Following the same steps as in the non-cooperative policy case, (see Eqs. (5.2), (5.5), (5.9) and (5.10)) we arrive at the following expressions for the optimal production decisions.

$$\begin{aligned} q^{R*} &= \frac{[a - t_Y - \mu(q^{R*})((t_E + \theta_d)\delta^R) + \mu_{q^R}(t_E(x^R + z) + \theta(d))](2b + \varphi^U)}{(2b + \varphi^U)(2b + \varphi^R + \mu_{q^{R*}} t_E \delta^R) - b^2} \\ &\quad + \frac{b[-a + \mu(q^{R*})((t_E + \theta_{q^U})\delta^U + t_Y + \psi_{q^U})]}{(2b + \varphi^U)(2b + \varphi^R + \mu_{q^{R*}} t_E \delta^R) - b^2} \end{aligned} \tag{5.17}$$

$$\begin{aligned} q^{U*} &= \frac{[a - \mu(q^{R*})((t_E + \theta_d)\delta^U + t_Y + \psi_{q^U})](2b + \varphi^R + \mu_{q^{R*}} t_E \delta^R)}{(2b + \varphi^U)(2b + \varphi^R + \mu_{q^{R*}} t_E \delta^R) - b^2} \\ &\quad + \frac{b[-a + t_Y + \mu(q^{R*})((t_E + \theta_{q^{U*}})\delta^R) - \mu_{q^{R*}}(t_E(x^R + z) + \theta(d))]}{(2b + \varphi^U)(2b + \varphi^R + \mu_{q^{R*}} t_E \delta^R) - b^2} \end{aligned} \tag{5.18}$$

which are the production levels at the CNE. ■

On the other hand there would be two more FOCs obtained by differentiating Eq. (5.15) with respect to x^R and z, that is $\frac{\partial \Pi^R}{\partial x^R} = 0$ and $\frac{\partial \Pi^R}{\partial z} = 0$ which give finally :

$$x^R = \frac{\mu(q^R)(t_E + \theta_d)}{\phi} \tag{5.19}$$

$$t_E = \frac{\mu(q^R)\theta_d}{1 - \alpha_R} \tag{5.20}$$

Lemma 3 In the case of a cooperative enforcement policy, using Eqs. (5.17) and (5.18) the size of unrecorded economy at the CNE can be defined by the following identity :

$$\frac{q^{U*}}{q^{R*} + q^{U*}} = \frac{V(2b + \varphi^R + \mu_{q^{R*}} t_E \delta^R) + Wb}{V(b + \varphi^R + \mu_{q^{R*}} t_E \delta^R) - W(b + \varphi^U)} \tag{5.21}$$

where $V = a - \mu(q^{R*})((t_E + \theta_d)\delta^U + t_Y + \psi_{q^U})$ and $W = -a + t_Y + \mu(q^{R*})((t_E + \theta_{q^{U*}})\delta^R) - \mu_{q^{R*}}(t_E(x^R + z) + \theta(d))$

Proposition 7 Suppose now, as in Proposition 3, that the regulatory authority decides to increase the environmental tax rate, then the extent of the unrecorded economy may be larger if :

$$t_E \geq \frac{\mu(q^R)[(\delta^U)(2b + \varphi^R) - b\delta^R] + \mu_{q^R}[\delta^R(-a + \mu(q^R)(\theta_d \delta^U + t_Y + \psi_{q^U})) + b(x^R + z)]}{2\mu_{q^R}\delta^R \mu(q^R)\delta^U} \tag{5.22}$$

Proof. From Eq. (5.14) it can be seen that $V_{t_E} < 0$. Besides, from the empirical study as we have concluded that $\mu_{q^R} > 0$, we find that $W_{t_E} > 0$. As a result, a rise of the environmental tax rate t_E will decrease the denominator of the Eq. (5.21). In the present case, taking the first derivative of the nominator with respect to t_E yields after some rearrangements the inequality given in Eq. (5.22). ■

The important point to bear in mind here is that the right hand side of Eq. (5.22) may be called as “the non-accelerating unrecorded activity rate of environmental tax” (henceforth NAUARET). If the enforcement agency choses a tax rate higher than the NAUARET then the size of unrecorded economy would likely be greater.

To close this section we suppose, as in the previous section, that market competition is characterized by a Stackelberg game instead of a Cournot game.

Proposition 8 If one solves the Stackelberg model, one finds that an increase in the environmental tax rate may have negative impact on the recorded activities if the following is satisfied :

$$\frac{\delta^R(2b+\varphi^U)-b\delta^U}{b\delta^U+(x+z)(2b+\varphi^U)} \geq \frac{\mu_{q^R}}{\mu(q^R)} \tag{5.23}$$

Proof. See the cooperative policy game in Appendix A.2. ■

Proposition 8 shows that in the Stackelberg framework, if the growth rate of the audit probability with respect to the recorded economic activities is smaller than a certain level (the threshold given in Eq. (5.23)), then a rise in the environmental tax may impede recorded economic activities. Here comes the importance of the forme of the probability-to-audit function.

5 Conclusion and additional remarks

The present chapter started out from the observation that although it varies across different countries, the size of unrecorded economy is very large in developing countries. Thus, in both theoretical and applied fields new models are needed that can better capture the effects of fiscal and environmental polices on the overall economy including both recorded and unrecorded activities. The chapter has employed a duopolistic competition model where behaviors of two representative firms (firm R and firm U) subject to environmental and fiscal regulation are analyzed in two different cases with respect to the existence of cooperation between environmental and fiscal regulatory authorities. Besides, two types of audit probability are considered : in the first case the probability is exogenous while it is a function of recorded economic activities in the second case. The form of this probability-to-audit function has been experimentally investigated using yearly time series data for Turkey.

In our view, the model specified in this way may be more realistic and structurally correct. In consequence the representation identified in the present chapter may be very useful in assessing possible effects of different environmental regulation schemes on firm behavior.

The results of this chapter can be summarized by third points. First, if the firm R is environmentally less efficient then the firm U and if the environmental enforcement agency audits the emissions randomly, then a shift in the environmental tax rate may increase the size of unrecorded economy. Second, in the periods of economic growth the regulatory authority should increase its audit effort to combat unrecorded economy. This holds at least for the case of Turkey. Last, there exists a threshold level for the environmental tax that we called non-accelerating unrecorded activity rate of environmental tax (NAUARET) above which the extent of the unrecorded economy may be larger due to an increase in the environmental tax rate.

Finally we point out that this study provides two main directions for future research : the theoretical one is to include unrecorded economy in the existing micro and macro economic models while the empirical one consists of an assessment of the long-run relationship between the size of unrecorded economy and recorded economic growth for developing countries, which will considerably increase our understanding of the environmental regulation-unrecorded economy nexus.

6 Appendixes

6.1 Appendix A. Stackelberg game

We consider a Stackelberg game in which the firm R moves first and then the firm U chooses its quantity to produce taking as given the production level of the firm R.

6.1.1 Appendix A.1. Non-cooperative policy game

The firm R has the following maximization problem :

$$\begin{aligned} Max\Pi^R &= [p(q^R + q^U(q^R)) - t_Y]q^R - c^R(q^R, x^R) - t_E z \\ & -\alpha_R[t_E(e^R(q^R, x^R) - z) + \theta(e^R(q^R, x^R) - z)] \end{aligned} \tag{5.24}$$

where $q^U(q^R)$ is substituted by the best response function of the firm U given in Eq. (5.10). Then, the maximum of Π^R with respect to q^R is found from the FOC, that is, $\frac{\partial \Pi^R}{\partial q^R} = 0$:

$$q^{R*} = \frac{(\varphi^U + b)a - (2b + \varphi^U)t_Y + (t_E + \theta_d)[b\alpha_U\delta^U - \alpha_R\delta^R(2b + \varphi^U)] + b\beta(t_Y + \psi_{q^U})}{\varphi^R(2b + \varphi^U) + 2b(b + \varphi^U)} \tag{5.25}$$

Using Eq. (5.25) to replace q^R in Eq. (5.10) gives after some tedious algebraic calculations the optimal production level of the firm U :

$$\begin{aligned} q^{U*} &= \frac{(\varphi^U + b)[ab - 2b(\alpha_U(t_E + \theta_{q^U})\delta^U + \beta(t_Y + \psi^{q^U}))] + (2b + \varphi^U)[\varphi^R(a - \alpha_U(t_E + \theta_{q^U})\delta^U)]}{(2b + \varphi^U)[\varphi^R(2b + \varphi^U) + 2b(b + \varphi^U)]} \\ & -\frac{(\varphi^R + b^2)\beta(t_Y + \psi^{q^U}) + b(t_E + \theta_{q^U})(b + \alpha_U\delta^U - \alpha_R\delta^R}{(2b + \varphi^U)[\varphi^R(2b + \varphi^U) + 2b(b + \varphi^U)]} \end{aligned} \tag{5.26}$$

Now for the proof of Proposition 5, first we use Lemma 1 to write $\alpha = \alpha_R = \alpha_U$ in Eq. (5.25), then calculate $\frac{\partial q^R}{\partial t_E}$ which gives finally :

$$\frac{\partial q^R}{\partial t_E} = -\alpha \frac{-b\delta^U + 2\delta^R b + \delta^R \varphi^U}{2\varphi^R b + \varphi^{R+U} + 2b\varphi^U + 2b^2}$$

We arrive at a conclusion that a shift in environmental tax may harm recorded economic activities ($\frac{\partial q^R}{\partial t_E} < 0$) if the firm R environmentally less efficient then the firm U (i.e. to produce same quantity the emission level of firm R is higher than that of firm U). More exactly the relationship between these two parameters should be as given below :

$$\frac{\delta^R}{\delta^U} > \frac{b}{2b + \varphi^U}$$

6.1.2 Appendix A.2. Cooperative policy game

The maximization problem that the firm R faces is now given by :

$$\begin{aligned} Max\Pi^R &= [p(q^R + q^U(q^R)) - t_Y]q^R - c^R(q^R, x^R) - t_E z \\ &\quad -\mu(q^R)[t_E(e^R(q^R, x^R) - z) + \theta(e^R(q^R, x^R) - z)] \end{aligned} \tag{5.27}$$

where $q^U(q^R) = \frac{a - bq^R - \mu(q^R)[(t_E + \theta_d)\delta^U + (t_Y + \psi_{q^U})]}{2b + \varphi^U}$. The FOC from $\frac{\partial \Pi^R}{\partial q^R} = 0$ gives

$$\begin{aligned} q^{R*} &= \frac{(\varphi^U + b)a - (2b + \varphi^U)t_Y + \mu(q^R)[(t_E + \theta_d)[b\delta^U - \delta^R(2b + \varphi^U)] + b(t_Y + \psi_{q^U})]}{(\varphi^R + \mu_{q^R} t_E \delta^R)(2b + \varphi^U) + 2b(b + \varphi^U)} \\ &\quad + \frac{\mu_{q^R}[b[(t_E + \theta_d)\delta^U + t_Y + \psi_{q^U}] - (2b + \varphi^U)(t_E(-x - z) + \theta(d))]}{(\varphi^R + \mu_{q^R} t_E \delta^R)(2b + \varphi^U) + 2b(b + \varphi^U)} \end{aligned} \tag{5.28}$$

Suppose there is a rise in the environmental tax, as the denominator of q^{R*} given in Eq. (5.28) increases, the sufficient condition for the proof of Proposition 8 can be deducted if the nominator decreases or remains stable. Solving this condition yields the threshold level stated in Eq. (5.23).

6.2 Appendix B. Empirical results

In this Appendix we determine the form of the probability-to-audit function ($\mu(q^R)$ from standard time series analysis based on the Turkish data. For this purpose we use the annual data for recorded economy (henceforth RE) taken from the Central Bank of the Republic of Turkey. The data used for the size of unrecorded economy (henceforth SUE) is the product of the estimations of unrecorded economy based on the environmental method from Karanfil and Ozkaya (2007). In order to check the robustness of the results both Savasan's (2003) and Schneider and Savasan's (2007) estimations of unrecorded economy are also used. All variables are denoted in real terms and converted into natural logarithms.

Fist of all, time series properties are checked by performing the augmented Dickey Fuller (ADF ; Dickey and Fuller, 1981) and the Phillips and Perron (PP ; Phillips and Perron, 1988) unit root tests based on the following model :

$$\Delta RE_t = \gamma_0 + \rho t + \gamma_1 RE_{t-1} + \sum_{i=1}^{k} \lambda_i \Delta RE_{t-i} + u_t \tag{5.29}$$

where RE is the variable to be tested, t is the trend variable, Δ is the first-difference operator and u_t is Gaussian white noise.

In both the cointegration technique developed by Engle and Granger (1987) and Johansen and Juselius' (1990) maximum likelihood procedure in order to establish a long-run equilibrium relationship between two or more variables, the variables should be all non-stationary and integrated of the same order. According to the unit root results reported in Table 5.2, we can conclude that the variables SUE and RE are both of them non-stationary and integrated of order 1, that is, I(1). Now, we can proceed to the next step which is to perform a cointegration test employing both

Tab. 5.2 – Results of unit root tests

Variable	Augmented Dickey-Fuller (ADF)		Phillips-Perron (PP)	
	Levels	First differences	Levels	First differences
SUE	-2.924	-4.772	-3.034	-4.869
RE	-2.536	-6.239	-2.675	-6.265
Critical values				
1%	-4.334	-3.723	-4.334	-3.723
5%	-3.580	-2.989	-3.580	-2.989
10%	-3.228	-2.625	-3.228	-2.625

the maximum eigenvalue and trace statistics.[7]

Tab. 5.3 – Johansen Test for the number of cointegrating relationships

Eigenvalue	$H_0 : r$	Trace	L Max	Critical values at 95%	
				Trace	L Max
0.530128	0	27.78722	21.90356	19.96	15.67
0.183628	1	5.883655	5.883655	9.24	9.24

r indicates the number of cointegrating relationships. The critical values for maximum eigenvalue and trace test statistics are given by Johansen and Juselius (1990).The model specification includes an intercept and no trend in the cointegrating equations.

The results from Table 5.3 suggest that with 95% confidence level, the variables SUE and RE are cointegrated which means that a long-run equilibrium relationship can be established between the variables involved. Furthermore from the estimated

[7]The aim of this Appendix is not so much to discuss the methodological issues relating to both unit root and cointegration tests. The reader is referred to Hamilton (1994, chapters 11 and 19) for a further information.

cointegrating vector the following equation can be written.

$$SUE = 0.954128RE - 7.903026$$

We see here clearly that SUE increases when there is a growth in the recorded economic activities.

We followed the Engle and Granger (1987) two-step procedure to assess the robustness of the cointegration test results. On the other hand, to be sure that the results are not biased due to the choice of data, we have also done work by using the data for unrecorded economy from Savasan (2003) and Schneider and Savasan (2007) and have reached very similar results ; the relevant variables are found to be cointegrated and the resulting cointegration equation is $SUE = 0.543394RE$, which establishes, once again, a positive linkage between SUE and RE. These additional results are available upon request from the author.

Conclusion générale

Nous avons essayé, dans les pages qui précèdent, de nous focaliser dans un premier temps, sur la relation empirique entre la consommation d'énergie et la croissance économique dans le cas de la Turquie, en prenant en compte l'importance que peut prendre la taille de l'économie non enregistrée dans cette relation, et ensuite, nous avons eu pour but d'apporter de nouveaux éléments de réflexion au débat sur la régulation environnementale en présence d'une part, de multiples défaillances de marché telles que l'asymétrie d'information et la pollution, et d'autre part, des activités économiques non enregistrées.

L'approche choisie pour aborder ce sujet s'est articulée autour de cinq axes de recherche, chacun d'entre eux correspondant à un chapitre : (1) Tester l'existence d'une relation de long terme entre la croissance économique et la consommation d'énergie au niveau national aussi bien qu'au niveau sectoriel. (2) Estimer la taille de l'économie non enregistrée utilisant des variables environnementales telles que les émissions de CO_2 et la surface des forêts proposant ainsi une approche inédite qui peut être qualifiée de "l'estimation environnementale de la taille d'économie non enregistrée". (3) Compte tenue de l'économie non enregistrée, réexaminer la relation énergie-croissance à l'aide des méthodes d'analyses des séries temporelles (tests de cointégration, de causalité au sens de Granger et de causalité instantanée).

(4) Déterminer les mécanismes d'incitation efficace de lutte contre les émissions polluantes lorsque celles-ci ne sont pas parfaitement connues par le régulateur. (5) Saisir l'impact de différentes pratiques de régulation environnementale sur le niveau d'activité dans l'économie enregistrée et non enregistrée.

Les trois premiers chapitres, qui constituent la partie empirique da la thèse, contribuent à la littérature économique en mettant en relation tridimensionnelle la consommation d'énergie, les émissions de CO_2 et la croissance économique (enregistrée et non enregistrée). D'une part, l'éstimation paramétrique d'une courbe de Kuznets environnementale pour les émissions de CO_2 en Turquie a permis de mettre en évidence l'existence d'une courbe concave ascendante, d'autre part les premiers résultats ont confirmé l'hypothèse de neutralité entre le PNB et la consommation d'énergie pour la période 1960-2003. Nous avons découvert que la taille de l'économie non enregistrée en Turquie varie entre 12 et 30 pour cent au cours de la période 1973-2003. Ce résultat indique que la taille de l'économie non enregistrée a considérablement augmenté au cours des trois dernières décennies. Si tel est bien le cas, il faut réétudier la relation de long terme entre la croissance économique et la consommation d'énergie tenant en compte, cette fois-ci, les activités économiques non enregistrées puisque celles-ci contribuent également à la consommation d'énergie dans le pays. Pour ce faire les tests de cointegration et de causalité au sens de Granger sont effectués dans deux modèles différents : avec et sans l'économie non enregistrée. Nous avons constaté qu'il y a une relation d'équilibre de long terme entre la consommation d'énergie et le PIB officiellement calculé. Dans ce cas-là, nous avons utilisé un VECM pour déterminer la direction de causalité et nous avons conclu qu'il y a une causalité de long terme qui va du PIB vers la consommation d'énergie. Nous avons donné des explications générales sur les résultats *inconsistants* obtenus au sujet de la direction de causalité. Nous voudrions simplement ajouter qu'ici, à notre avis, l'inconsistance entre la conclusion du premier chapitre (i.e. neutralité PNB-énergie) et l'un des résultats importants du troisième chapitre (i.e. causalité PIB-énergie et PNB-énergie) vient du fait que dans le début de la période considérée dans le premier chapitre, il y a une forte accumulation de capital dans le secteur industriel, qui a du changer considérablement la fonction de production dans l'industrie turque, et qu'en revanche, la période de 1960-1972 n'est pas couverte dans l'analyse empirique proposée dans le troisième chapitre et en conséquence la fonction de production durant une période de 33 ans, de 1973 à 2005, semble être relativement stable. Cela montre clairement que la période considérée affecte significativement les résultats : même si on utilise mêmes techniques avec les mêmes variables économiques, lorsque deux périodes ont des profils économiques et énergétiques différents, les résultats divergent, ce qui n'est pas surprenant. D'autres résultats de la recherche dans cette partie empirique indiquent, en termes de la causalité au sens de Granger, que l'hypothèse de neutralité semble être corroborée entre le *vrai* PIB (c'est-à-dire la somme de ses composantes officielles et non enregistrées) et la consommation d'énergie et qu'il y a certaines relations causales qui vont de l'activité économique (PNB et valeur ajoutée dans l'industrie) vers la consommation d'électricité et de produits pétroliers.

Pour éviter toute confusion et mauvaise interprétation il faut préciser ce que nous entendons par la causalité au sens de Granger qui est largement utilisée dans les analyses économétriques du premier et du troisième chapitres. Granger (1988, p.200) donne la définition de causalité en terme de prévisibilité : "*if* y_t *causes* x_t*, then* x_{t+1} *is better forecast if the information in* y_{t-j} *is used than if it is not used*". Il faut donc interpréter la causalité qui va de la croissance économique vers la consommation d'énergie de la façon suivante : la croissance économique précède la consommation d'énergie et donc la première peut être le principal indicateur de la deuxième. Par contre, il se peut que ces deux variables sont déterminées par d'autres variables macroéconomiques et donc ne sont pas directement liées.

Dans cette partie empirique, chaque chapitre fournit une discussion des implications possibles de ces résultats. Pour résumer, nous pouvons dire que pour satisfaire la demande énergétique croissante, une politique nationale d'économie d'énergie (par exemple, progrès technique économisant l'énergie, commutation de combustible, production d'énergie renouvelable) peut être appliquée sans avoir un impact négatif sur les activités économiques enregistrées. Une telle politique doit également accorder beaucoup d'attention à l'environnement et donc sera d'autant plus efficace si elle est accompagnée d'une politique de régulation environnementale. Et c'est là justement le problème que nous posons dans les deux derniers chapitres de cette présente thèse. Dans le quatrième chapitre nous avons mis au cœur de notre réflexion théorique les modèles d'asymétrie d'information, qui nous permettent d'apporter quelques éléments de réponse sur la façon dont la théorie économique peut expliquer les impacts des politiques environnementales sur les décisions des entreprises telles que l'investissement en énergie propre et le niveau d'émission polluante. La conclusion que nous tirons de cette analyse théorique est que les firmes déploient de véritables efforts pour se conformer aux règlements environnementaux si le régulateur applique un mécanisme d'application approprié au lieu d'un système de contrôle aléatoire des émissions polluantes. Finalement, le développement de modèles de concurrence duopolistique a fait l'objet du cinquième chapitre où nous avons étudié d'une part la coordination et la coopération entre les autorités environnementales et fiscales, et d'autre part, les effets possibles de différents systèmes de contrôle environnemental sur la production dans l'économie à la fois enregistrée et non enregistrée. Notre conclusion dans ce dernier chapitre peut tenir en quelques alinéas. Une hausse du taux de la taxe environnementale peut avoir un effet néfaste sur la production dans l'économie enregistrée si les firmes y sont moins efficaces (du point de vue de l'émission polluante par unité de bien produit) que les firmes exerçant une activité non enregistrée. De plus, il peut exister un seuil pour le niveau de la taxe environnementale, et si ce seuil est dépassé, la taille de l'économie non enregistrée peut augmenter.

On peut croire que nous avons eu un peu d'intérêt critique voir polémique à écrire certaines parties de cette thèse. Nous ne pouvons pas nier, cependant, que notre enthousiasme et pour les conclusions avancées par de nombreux travaux empiriques sur la relation entre la croissance économique et la consommation d'énergie dans les pays en voie de développement, et pour l'état présent de la théorie de la régulation environnementale est particulièrement modéré. Nous avons essayé, autant que possible, de montrer, pourquoi il est nécessaire de considérer les activités économiques non enregistrées dans les études empiriques aussi bien que théoriques.

Il est évident que les analyses proposées dans le cadre de cette thèse de doctorat ne sont pas exhaustives. Par contre, nous espérons que notre tentative de formuler une réflexion critique sur les interactions entre la consommation d'énergie, la taille de l'économie non enregistrée et la régulation environnementale stimulera en même temps les investigations empiriques et les discussions théoriques de ce champ de recherche. Nous sommes sûrs du fait que les investigations empiriques sur le sujet et les modèles développés de la façon proposée dans cette thèse sont plus réalistes et structurellement plus corrects. C'est la raison pour laquelle nous exprimons, *in fine*, le souhait que notre analyse puisse indiquer la voie à suivre pour des travaux ultérieurs et permettre ainsi des recherches fécondes dans ce domaine.

Annexe

Tab. 5.4 – Index de l'efficacité énergétique

	Pays(énergie/PIB)	1990	Pays(énergie/PIB)	2000	Pays(énergie/PIB)	2005
1	Hong Kong	0.000	Hong Kong	0.000	Hong Kong	0.000
2	Japon	0.002	Suisse	0.002	Suisse	0.006
3	Suisse	0.003	Japon	0.004	Japon	0.006
4	Danemark	0.009	Danemark	0.005	Danemark	0.009
5	Uruguay	0.009	Irlande	0.011	Irlande	0.011
6	Gibraltar	0.010	Uruguay	0.011	Uruguay	0.015
7	Italie	0.011	Autriche	0.011	Royaume-Uni	0.018
8	Autriche	0.013	Norvège	0.012	Israël	0.021
9	Israël	0.015	Italie	0.013	Italie	0.024
10	Norvège	0.016	Royaume-Uni	0.014	Autriche	0.025
11	Royaume-Uni	0.016	Israël	0.014	Grèce	0.027
12	Grèce	0.017	Allemagne	0.017	Norvège	0.028
13	Espagne	0.020	Luxembourg	0.018	Allemagne	0.028
14	France	0.020	Grèce	0.019	Panama	0.030
15	Portugal	0.020	France	0.020	Suède	0.033
16	Panama	0.021	Pays-Bas	0.021	France	0.034
17	Costa Rica	0.021	Suède	0.021	Costa Rica	0.035
18	Irlande	0.021	Malte	0.022	Pays-Bas	0.036
19	Allemagne	0.024	Costa Rica	0.023	Luxembourg	0.037
20	Pays-Bas	0.025	Espagne	0.024	Argentine	0.037
21	Suède	0.026	Argentine	0.025	Pérou	0.039
22	Maroc	0.028	Panama	0.026	Etats-Unis.	0.040
23	Argentine	0.028	Portugal	0.026	Espagne	0.040
24	Belgique	0.030	Pérou	0.028	Belgique	0.044
25	Chypre	0.031	Etats-Unis.	0.029	Botswana	0.046
26	Etats-Unis.	0.032	Singapour	0.029	Portugal	0.046
27	Liban	0.032	Gibraltar	0.030	Chypre	0.049
28	Pérou	0.033	Belgique	0.032	Gibraltar	0.050
29	Luxembourg	0.035	Mexique	0.033	Malte	0.050
30	Taïwan	0.035	Congo	0.034	Finlande	0.053
31	Brésil	0.035	Chypre	0.035	Australie	0.055
32	Finlande	0.035	Taïwan	0.035	Singapour	0.057
33	Singapour	0.037	Finlande	0.035	Nouvelle-Zélande	0.058
34	Mexique	0.037	Australie	0.037	Liban	0.060
35	El Salvador	0.038	Botswana	0.041	Mexique	0.060
36	Australie	0.039	Maroc	0.041	Colombie	0.064
37	Gabon	0.040	Liban	0.042	Taïwan	0.067
38	Islande	0.041	Brésil	0.043	Congo	0.068
39	Malte	0.042	El Salvador	0.043	Brésil	0.072
40	Corée du Sud	0.042	Gabon	0.044	République dominicaine	0.072
41	Nouvelle-Zélande	0.045	Colombie	0.047	El Salvador	0.073
42	Slovénie	0.046	Slovénie	0.049	Chili	0.073
43	Chili	0.046	Nouvelle-Zélande	0.050	Gabon	0.074
44	Guatemala	0.046	Canada	0.050	Slovénie	0.074
45	Oman	0.048	Chili	0.050	Canada	0.077
46	Haïti	0.050	Guatemala	0.055	Corée du Sud	0.079
47	République dominicaine	0.051	Corée du Sud	0.056	Maroc	0.080
48	Botswana	0.051	Islande	0.057	Islande	0.081
49	**Turquie**	0.051	**Turquie**	0.059	**Turquie**	0.082
50	Colombie	0.052	Tunisie	0.059	Cuba	0.083
51	Congo	0.052	République dominicaine	0.060	Tunisie	0.083
52	Canada	0.053	Bangladesh	0.061	Guatemala	0.088
53	Libye	0.057	Cuba	0.065	Croatie	0.094
54	Croatie	0.059	Croatie	0.066	Bangladesh	0.097
55	Arabie saoudite	0.060	Egypte	0.073	Lettonie	0.102
56	Bangladesh	0.062	Venezuela	0.078	Libye	0.110
57	Jamaïque	0.063	Oman	0.079	Jamaïque	0.112
58	Tunisie	0.065	Jamaïque	0.079	Émirats arabes unis	0.116
59	Koweït	0.065	Albanie	0.080	Venezuela	0.120
60	Équateur	0.066	Libye	0.080	Hongrie	0.121

Tab. 5.4 (suite) – Index de l'efficacité énergétique

	Pays(énergie/PIB)	1990	Pays(énergie/PIB)	2000	Pays(énergie/PIB)	2005
61	Venezuela	0.067	Sri Lanka	0.081	Pologne	0.121
62	Yémen	0.068	Lettonie	0.081	Philippines	0.124
63	Philippines	0.068	Honduras	0.083	Sri Lanka	0.124
64	Bolivie	0.070	Émirats arabes unis	0.083	Paraguay	0.129
65	Brunei	0.071	Yémen	0.085	Algérie	0.131
66	Egypte	0.071	Équateur	0.086	Albanie	0.131
67	Émirats arabes unis	0.071	Hongrie	0.086	Équateur	0.134
68	Malaisie	0.076	Pologne	0.086	Egypte	0.134
69	Algérie	0.077	Algérie	0.088	Lituanie	0.137
70	Paraguay	0.077	Haïti	0.090	Koweït	0.143
71	Côte d'Ivoire	0.079	Koweït	0.090	Bolivie	0.145
72	Cuba	0.079	Paraguay	0.091	Brunei	0.145
73	Thaïlande	0.083	Philippines	0.094	Honduras	0.145
74	Honduras	0.085	Arabie saoudite	0.095	Malaisie	0.145
75	Sri Lanka	0.085	Malaisie	0.095	Sénégal	0.147
76	Cameroun	0.087	Bolivie	0.099	Cameroun	0.156
77	Irak	0.088	Brunei	0.099	Yémen	0.164
78	Hongrie	0.100	Sénégal	0.102	Oman	0.166
79	Jordanie	0.107	Thaïlande	0.103	Arabie saoudite	0.167
80	Sénégal	0.107	Jordanie	0.104	Jordanie	0.169
81	Qatar	0.113	Lituanie	0.106	Thaïlande	0.174
82	Angola	0.118	Cameroun	0.108	Estonie	0.177
83	Lettonie	0.119	Antilles néerlandaises	0.110	Angola	0.183
84	Nicaragua	0.120	Côte d'Ivoire	0.113	République tchèque	0.184
85	Antilles néerlandaises	0.127	Qatar	0.115	Qatar	0.185
86	Afrique du Sud	0.133	Nicaragua	0.121	Haïti	0.187
87	Albanie	0.134	République tchèque	0.124	Antilles néerlandaises	0.203
88	Pologne	0.137	Bahreïn	0.138	Nicaragua	0.204
89	Pakistan	0.142	Bosnie-et-Herzégovine	0.141	Slovaquie	0.206
90	République tchèque	0.145	Estonie	0.147	Géorgie	0.207
91	Indonésie	0.155	Afrique du Sud	0.149	Côte d'Ivoire	0.210
92	Iran	0.161	Slovaquie	0.155	Arménie	0.211
93	Lituanie	0.166	Angola	0.155	Bahreïn	0.216
94	Trinidad-et-Tobago	0.168	Pakistan	0.156	Bosnie-et-Herzégovine	0.217
95	Bahreïn	0.173	Bénin	0.160	Romanie	0.221
96	Syrie	0.173	Chine	0.166	Afrique du Sud	0.226
97	Slovaquie	0.191	Indonésie	0.167	Syrie	0.226
98	Kenya	0.199	Géorgie	0.171	Pakistan	0.233
99	Inde	0.200	Syrie	0.173	Inde	0.237
100	Bénin	0.200	Romanie	0.178	Indonésie	0.246
101	Togo	0.230	Inde	0.182	Chine	0.261
102	Zimbabwe	0.238	Irak	0.183	Bénin	0.270
103	Romanie	0.242	Arménie	0.199	Birmanie	0.280
104	Tanzanie	0.247	Soudan	0.205	Soudan	0.321
105	Soudan	0.257	Iran	0.216	Kenya	0.333
106	Géorgie	0.260	Kenya	0.219	Trinidad-et-Tobago	0.334
107	Rép. démoc. du Congo	0.267	Vietnam	0.222	Vietnam	0.336
108	Estonie	0.278	Trinidad-et-Tobago	0.224	Iran	0.361
109	Vietnam	0.279	Birmanie	0.239	Bulgarie	0.369
110	Ghana	0.282	Togo	0.248	Togo	0.394
111	Népal	0.299	Zimbabwe	0.253	Azerbaïdjan	0.415
112	Zambie	0.314	Tanzanie	0.279	Ghana	0.418
113	Bulgarie	0.335	Bulgarie	0.280	Népal	0.431
114	Chine	0.338	Népal	0.280	Belarus	0.434
115	Nigeria	0.354	Serbie	0.293	Serbie	0.458
116	Birmanie	0.380	Ghana	0.300	Irak	0.483
117	Tadjikistan	0.381	Kirghizistan	0.340	Tanzanie	0.484
118	Russie	0.400	Belarus	0.369	Kirghizistan	0.513
119	Serbie	0.400	Zambie	0.370	Nigeria	0.517
120	Ethiopie	0.428	Nigeria	0.371	Kazakhstan	0.527
121	Moldavie	0.489	Kazakhstan	0.405	Zambie	0.529
122	Kazakhstan	0.495	Azerbaïdjan	0.420	Mozambique	0.533
123	Arménie	0.499	Moldavie	0.429	Zimbabwe	0.534
124	Azerbaïdjan	0.516	Mozambique	0.442	Russie	0.559
125	Belarus	0.521	Russie	0.456	Moldavie	0.597
126	Mozambique	0.562	Ethiopie	0.460	Mongolie	0.629
127	Ouzbékistan	0.588	Mongolie	0.475	Ethiopie	0.657
128	Ukraine	0.624	Tadjikistan	0.567	Tadjikistan	0.683
129	Mongolie	0.635	Rép. démoc. du Congo	0.670	Ouzbékistan	0.804
130	Kirghizistan	0.662	Ouzbékistan	0.716	Turkménistan	0.909
131	Turkménistan	0.945	Ukraine	0.843	Ukraine	0.977
132	Bosnie-et-Herzégovine	1.000	Turkménistan	1.000	Rép. démoc. du Congo	1.000

Tab. 5.5 – Index de l'efficacité environnementale

	Pays(CO_2/énergie)	1990	Pays(CO_2/énergie)	2000	Pays(CO_2/énergie)	2005
1	Ethiopie	0.000	Rép. démoc. du Congo	0.000	Rép. démoc. du Congo	0.000
2	Mozambique	0.001	Mozambique	0.001	Mozambique	0.004
3	Bénin	0.002	Ethiopie	0.007	Tanzanie	0.018
4	Népal	0.002	Tanzanie	0.013	Ethiopie	0.025
5	Tanzanie	0.008	Zambie	0.035	Zambie	0.046
6	Rép. démoc. du Congo	0.028	Népal	0.064	Népal	0.055
7	Birmanie	0.062	Soudan	0.070	Cameroun	0.079
8	Togo	0.068	Cameroun	0.081	Togo	0.099
9	Nigeria	0.073	Nigeria	0.087	Nigeria	0.109
10	Zambie	0.091	Togo	0.104	Soudan	0.117
11	Ghana	0.100	Kenya	0.123	Kenya	0.121
12	Kenya	0.100	Birmanie	0.138	Islande	0.131
13	Soudan	0.103	Angola	0.140	Haïti	0.148
14	Cameroun	0.106	Ghana	0.142	Birmanie	0.170
15	Haïti	0.124	Islande	0.144	Ghana	0.181
16	Côte d'Ivoire	0.125	Haïti	0.150	Côte d'Ivoire	0.183
17	Paraguay	0.131	Congo	0.151	Congo	0.183
18	Angola	0.139	Bénin	0.154	Angola	0.199
19	Congo	0.142	Paraguay	0.192	Paraguay	0.202
20	Sri Lanka	0.147	Gabon	0.206	Bénin	0.232
21	Vietnam	0.152	Côte d'Ivoire	0.206	Suède	0.233
22	Gabon	0.160	Suède	0.266	Gabon	0.251
23	Guatemala	0.163	Vietnam	0.282	Zimbabwe	0.256
24	El Salvador	0.195	Guatemala	0.300	Norvège	0.281
25	Nicaragua	0.198	Zimbabwe	0.309	Géorgie	0.288
26	Islande	0.202	El Salvador	0.313	Nicaragua	0.302
27	Honduras	0.204	Nicaragua	0.313	El Salvador	0.316
28	Sénégal	0.222	Norvège	0.324	Sri Lanka	0.324
29	Bangladesh	0.252	Sri Lanka	0.328	Guatemala	0.325
30	Suède	0.269	Bangladesh	0.331	France	0.351
31	Costa Rica	0.315	Sénégal	0.333	Costa Rica	0.355
32	Norvège	0.328	Costa Rica	0.339	Singapour	0.358
33	Pakistan	0.335	Honduras	0.363	Bangladesh	0.378
34	Indonésie	0.338	France	0.364	Sénégal	0.383
35	Philippines	0.340	Tadjikistan	0.366	Pakistan	0.391
36	Brésil	0.357	Géorgie	0.378	Lettonie	0.392
37	Nouvelle-Zélande	0.389	Pakistan	0.381	Lituanie	0.394
38	France	0.390	Bolivie	0.385	Vietnam	0.395
39	Cuba	0.412	Lituanie	0.393	Brésil	0.397
40	Panama	0.414	Suisse	0.404	Finlande	0.400
41	Suisse	0.416	Philippines	0.407	Arménie	0.409
42	Uruguay	0.419	Finlande	0.412	Tadjikistan	0.415
43	Zimbabwe	0.430	Brésil	0.412	Suisse	0.420
44	Thaïlande	0.454	Arménie	0.414	Honduras	0.421
45	Colombie	0.461	Singapour	0.431	Philippines	0.435
46	Inde	0.466	Lettonie	0.434	Uruguay	0.463
47	République dominicaine	0.469	Uruguay	0.434	Trinidad-et-Tobago	0.468
48	Brunei	0.471	Albanie	0.441	Indonésie	0.487
49	Trinidad-et-Tobago	0.480	Indonésie	0.444	Albanie	0.492
50	Finlande	0.480	Nouvelle-Zélande	0.456	Brunei	0.495
51	Antilles néerlandaises	0.490	Panama	0.458	Oman	0.496
52	Pérou	0.492	Trinidad-et-Tobago	0.461	Kirghizistan	0.501
53	Bolivie	0.502	Brunei	0.463	Belgique	0.507
54	Canada	0.525	Kirghizistan	0.476	Chili	0.510
55	Lituanie	0.527	Belgique	0.514	Canada	0.520
56	Tadjikistan	0.539	Oman	0.522	Slovaquie	0.524
57	Malaisie	0.540	Chili	0.524	Pérou	0.530
58	Équateur	0.554	Inde	0.539	Nouvelle-Zélande	0.532
59	Singapour	0.554	Pérou	0.540	Ukraine	0.535
60	Oman	0.560	Slovaquie	0.541	Hongrie	0.536
61	Argentine	0.561	Thaïlande	0.542	Colombie	0.541
62	Tunisie	0.562	Canada	0.545	Corée du Sud	0.542
63	Belgique	0.570	Ukraine	0.546	Slovénie	0.548
64	Émirats arabes unis	0.574	Cuba	0.552	Inde	0.552
65	Portugal	0.576	Équateur	0.554	Thaïlande	0.554
66	Slovénie	0.577	Argentine	0.556	Panama	0.565
67	Chili	0.587	Slovénie	0.557	Mexique	0.572
68	Qatar	0.588	Autriche	0.563	Argentine	0.573
69	Espagne	0.588	Malaisie	0.564	Moldavie	0.578
70	Algérie	0.593	Luxembourg	0.566	Bolivie	0.579

Tab. 5.5 (suite) – Index de l'efficacité environnementale

	Pays(CO_2/énergie)	**1990**	**Pays(CO_2/énergie)**	**2000**	**Pays(CO_2/énergie)**	**2005**
71	Autriche	0.596	Colombie	0.569	Pays-Bas	0.580
72	Botswana	0.596	Hongrie	0.571	Équateur	0.581
73	Géorgie	0.605	Japon	0.571	Autriche	0.583
74	Albanie	0.609	République dominicaine	0.573	Malaisie	0.584
75	Mexique	0.611	Royaume-Uni	0.574	Bahreïn	0.585
76	Taïwan	0.613	Corée du Sud	0.574	Hong Kong	0.585
77	Pays-Bas	0.613	Bulgarie	0.579	Azerbaïdjan	0.587
78	Libye	0.614	Belarus	0.579	Royaume-Uni	0.588
79	Lettonie	0.614	Moldavie	0.581	Botswana	0.590
80	Japon	0.617	Venezuela	0.582	Arabie saoudite	0.592
81	Turkménistan	0.618	Qatar	0.582	Tunisie	0.593
82	Croatie	0.620	Bahreïn	0.583	Belarus	0.593
83	Venezuela	0.620	Botswana	0.585	Japon	0.594
84	Chypre	0.621	Algérie	0.586	République dominicaine	0.596
85	Azerbaïdjan	0.627	Pays-Bas	0.589	Qatar	0.597
86	Bahreïn	0.628	Espagne	0.590	Bulgarie	0.597
87	**Turquie**	0.630	Croatie	0.590	Antilles néerlandaises	0.602
88	Corée du Sud	0.631	Antilles néerlandaises	0.594	Portugal	0.603
89	Jamaïque	0.633	Ouzbékistan	0.597	Cuba	0.606
90	Hongrie	0.642	Émirats arabes unis	0.599	Venezuela	0.607
91	Egypte	0.645	Libye	0.601	Croatie	0.608
92	Russie	0.648	Arabie saoudite	0.601	Ouzbékistan	0.609
93	Yémen	0.652	Portugal	0.612	Émirats arabes unis	0.612
94	Etats-Unis.	0.654	Tunisie	0.613	Espagne	0.612
95	Iran	0.663	Mexique	0.613	Allemagne	0.614
96	Chine	0.667	Romanie	0.615	Romanie	0.617
97	Belarus	0.667	Egypte	0.623	Luxembourg	0.619
98	Arménie	0.675	Allemagne	0.624	Libye	0.621
99	Ouzbékistan	0.675	Azerbaïdjan	0.635	Russie	0.622
100	Arabie saoudite	0.677	Italie	0.636	Egypte	0.627
101	Bulgarie	0.680	Russie	0.638	Danemark	0.631
102	Royaume-Uni	0.685	Koweït	0.638	Algérie	0.632
103	Jordanie	0.686	Etats-Unis.	0.639	Italie	0.639
104	Syrie	0.692	Jamaïque	0.644	Taïwan	0.644
105	Slovaquie	0.697	Hong Kong	0.647	Etats-Unis.	0.649
106	Romanie	0.698	Turkménistan	0.649	Iran	0.654
107	Italie	0.703	Iran	0.666	Jamaïque	0.656
108	Gibraltar	0.705	Taïwan	0.671	Jordanie	0.659
109	Ukraine	0.706	Danemark	0.672	Turkménistan	0.664
110	Allemagne	0.709	Syrie	0.676	**Turquie**	0.672
111	Liban	0.723	Chypre	0.676	Afrique du Sud	0.677
112	Israël	0.725	**Turquie**	0.683	République tchèque	0.684
113	Irak	0.725	Afrique du Sud	0.699	Koweït	0.695
114	Afrique du Sud	0.730	Yémen	0.706	Syrie	0.699
115	Danemark	0.741	Chine	0.716	Irak	0.722
116	Maroc	0.766	Jordanie	0.717	Chypre	0.724
117	Luxembourg	0.774	Liban	0.730	Malte	0.729
118	Australie	0.778	Malte	0.747	Yémen	0.729
119	Malte	0.779	Israël	0.753	Liban	0.745
120	Irlande	0.783	Irlande	0.756	Irlande	0.753
121	Kirghizistan	0.787	Irak	0.762	Chine	0.776
122	Serbie	0.793	République tchèque	0.763	Kazakhstan	0.777
123	Koweït	0.794	Gibraltar	0.772	Gibraltar	0.782
124	Moldavie	0.797	Maroc	0.774	Maroc	0.789
125	Hong Kong	0.814	Kazakhstan	0.791	Serbie	0.797
126	République tchèque	0.827	Serbie	0.791	Israël	0.810
127	Kazakhstan	0.833	Australie	0.804	Grèce	0.815
128	Grèce	0.838	Grèce	0.827	Australie	0.815
129	Bosnie-et-Herzégovine	0.889	Bosnie-et-Herzégovine	0.833	Estonie	0.826
130	Pologne	0.925	Estonie	0.841	Pologne	0.841
131	Mongolie	0.993	Pologne	0.860	Bosnie-et-Herzégovine	0.849
132	Estonie	1.000	Mongolie	1.000	Mongolie	1.000

TAB. 5.6 – Index général

	Pays(index général)	1990	Pays(index général)	2000	Pays(index général)	2005
1	Haïti	0.087	Congo	0.093	Islande	0.106
2	Cameroun	0.097	Cameroun	0.094	Cameroun	0.117
3	Congo	0.097	Islande	0.100	Congo	0.126
4	Gabon	0.100	Haïti	0.120	Suède	0.133
5	Bénin	0.101	Gabon	0.125	Norvège	0.154
6	Côte d'Ivoire	0.102	Soudan	0.137	Gabon	0.162
7	Paraguay	0.104	Paraguay	0.141	Paraguay	0.166
8	Guatemala	0.105	Suède	0.144	Haïti	0.167
9	Sri Lanka	0.116	Tanzanie	0.146	Angola	0.191
10	El Salvador	0.116	Angola	0.148	France	0.192
11	Islande	0.121	Bénin	0.157	El Salvador	0.194
12	Tanzanie	0.127	Côte d'Ivoire	0.160	Costa Rica	0.195
13	Angola	0.129	Norvège	0.168	Côte d'Ivoire	0.197
14	Honduras	0.144	Kenya	0.171	Guatemala	0.207
15	Suède	0.148	Népal	0.172	Singapour	0.208
16	Rép. démoc. du Congo	0.148	Togo	0.176	Suisse	0.213
17	Togo	0.149	Guatemala	0.178	Soudan	0.219
18	Kenya	0.149	El Salvador	0.178	Sri Lanka	0.224
19	Népal	0.151	Costa Rica	0.181	Birmanie	0.225
20	Bangladesh	0.157	Birmanie	0.189	Finlande	0.227
21	Nicaragua	0.159	France	0.192	Kenya	0.227
22	Sénégal	0.165	Bangladesh	0.196	Brésil	0.234
23	Costa Rica	0.168	Zambie	0.203	Bangladesh	0.237
24	Norvège	0.172	Suisse	0.203	Uruguay	0.239
25	Soudan	0.180	Sri Lanka	0.204	Népal	0.243
26	Ghana	0.191	Nicaragua	0.217	Togo	0.246
27	Brésil	0.196	Sénégal	0.218	Lettonie	0.247
28	Zambie	0.202	Ghana	0.221	Géorgie	0.247
29	Philippines	0.204	Mozambique	0.221	Bénin	0.251
30	France	0.205	Uruguay	0.222	Tanzanie	0.251
31	Suisse	0.209	Honduras	0.223	Nicaragua	0.253
32	Nigeria	0.214	Finlande	0.224	Sénégal	0.265
33	Ethiopie	0.214	Brésil	0.228	Lituanie	0.265
34	Uruguay	0.214	Nigeria	0.229	Mozambique	0.268
35	Vietnam	0.216	Singapour	0.230	Belgique	0.276
36	Panama	0.217	Ethiopie	0.234	Philippines	0.279
37	Nouvelle-Zélande	0.217	Panama	0.242	Honduras	0.283
38	Birmanie	0.221	Bolivie	0.242	Pérou	0.285
39	Pakistan	0.238	Lituanie	0.249	Zambie	0.288
40	Cuba	0.246	Philippines	0.251	Chili	0.291
41	Indonésie	0.247	Vietnam	0.252	Hong Kong	0.292
42	Colombie	0.256	Nouvelle-Zélande	0.253	Nouvelle-Zélande	0.295
43	Finlande	0.258	Lettonie	0.258	Panama	0.298
44	République dominicaine	0.260	Albanie	0.260	Canada	0.298
45	Pérou	0.263	Pakistan	0.268	Ghana	0.300
46	Thaïlande	0.269	Belgique	0.273	Japon	0.300
47	Brunei	0.271	Géorgie	0.275	Colombie	0.302
48	Mozambique	0.282	Zimbabwe	0.281	Royaume-Uni	0.303
49	Bolivie	0.286	Brunei	0.281	Autriche	0.304
50	Canada	0.289	Pérou	0.284	Argentine	0.305
51	Argentine	0.295	Chili	0.287	Pays-Bas	0.308
52	Singapour	0.296	Autriche	0.287	Arménie	0.310
53	Portugal	0.298	Japon	0.287	Corée du Sud	0.311
54	Belgique	0.300	Argentine	0.290	Slovénie	0.311
55	Espagne	0.304	Luxembourg	0.292	Albanie	0.312
56	Autriche	0.304	Royaume-Uni	0.294	Pakistan	0.312
57	Oman	0.304	Canada	0.298	Nigeria	0.313
58	Malaisie	0.308	Oman	0.300	Mexique	0.316
59	Antilles néerlandaises	0.308	Slovénie	0.303	Botswana	0.318
60	Japon	0.309	Pays-Bas	0.305	Brunei	0.320
61	Équateur	0.310	Indonésie	0.306	Danemark	0.320
62	Slovénie	0.311	Arménie	0.306	Allemagne	0.321
63	Tunisie	0.314	Espagne	0.307	Portugal	0.325
64	Chili	0.316	Colombie	0.308	Espagne	0.326
65	Pays-Bas	0.319	Cuba	0.308	Luxembourg	0.328
66	Émirats arabes unis	0.322	Botswana	0.313	Hongrie	0.329
67	Botswana	0.323	Corée du Sud	0.315	Oman	0.331
68	Trinidad-et-Tobago	0.324	République dominicaine	0.317	Italie	0.332
69	Taïwan	0.324	Portugal	0.319	République dominicaine	0.334
70	Mexique	0.324	Équateur	0.320	Tunisie	0.338

TAB. 5.6 (suite) – Index général

	Pays(index général)	1990	Pays(index général)	2000	Pays(index général)	2005
71	Chypre	0.326	Allemagne	0.321	Ethiopie	0.341
72	Inde	0.333	Thaïlande	0.323	Etats-Unis.	0.344
73	Zimbabwe	0.334	Mexique	0.323	Cuba	0.344
74	Algérie	0.335	Hong Kong	0.323	Croatie	0.351
75	Libye	0.335	Italie	0.324	Taïwan	0.356
76	Corée du Sud	0.337	Croatie	0.328	Équateur	0.357
77	Croatie	0.340	Hongrie	0.328	Bolivie	0.362
78	**Turquie**	0.341	Malaisie	0.330	Venezuela	0.364
79	Etats-Unis.	0.343	Venezuela	0.330	Émirats arabes unis	0.364
80	Venezuela	0.343	Etats-Unis.	0.334	Thaïlande	0.364
81	Lituanie	0.347	Rép. démoc. du Congo	0.335	Malaisie	0.365
82	Jamaïque	0.348	Tunisie	0.336	Slovaquie	0.365
83	Qatar	0.350	Algérie	0.337	Libye	0.365
84	Royaume-Uni	0.351	Danemark	0.339	Vietnam	0.366
85	Italie	0.357	Libye	0.341	Indonésie	0.367
86	Gibraltar	0.358	Émirats arabes unis	0.341	**Turquie**	0.377
87	Egypte	0.358	Trinidad-et-Tobago	0.342	Arabie saoudite	0.379
88	Yémen	0.360	Egypte	0.348	Egypte	0.381
89	Lettonie	0.367	Slovaquie	0.348	Algérie	0.381
90	Allemagne	0.367	Arabie saoudite	0.348	Irlande	0.382
91	Arabie saoudite	0.368	Qatar	0.349	Jamaïque	0.384
92	Israël	0.370	Antilles néerlandaises	0.352	Chypre	0.386
93	Hongrie	0.371	Taïwan	0.353	Malte	0.389
94	Albanie	0.371	Chypre	0.355	Qatar	0.391
95	Danemark	0.375	Inde	0.361	Inde	0.395
96	Liban	0.378	Bahreïn	0.361	Zimbabwe	0.395
97	Jordanie	0.397	Jamaïque	0.362	Bahreïn	0.400
98	Maroc	0.397	Koweït	0.364	Trinidad-et-Tobago	0.401
99	Bahreïn	0.401	**Turquie**	0.371	Liban	0.402
100	Irlande	0.402	Irlande	0.384	Antilles néerlandaises	0.403
101	Luxembourg	0.404	Israël	0.384	Jordanie	0.414
102	Irak	0.407	Malte	0.384	Israël	0.416
103	Hong Kong	0.407	Liban	0.386	Gibraltar	0.416
104	Australie	0.409	Yémen	0.395	Koweït	0.419
105	Malte	0.411	Romanie	0.396	Romanie	0.419
106	Iran	0.412	Gibraltar	0.401	Grèce	0.421
107	Grèce	0.428	Maroc	0.408	République tchèque	0.434
108	Koweït	0.429	Kirghizistan	0.408	Maroc	0.434
109	Afrique du Sud	0.432	Jordanie	0.410	Australie	0.435
110	Géorgie	0.432	Australie	0.420	Yémen	0.447
111	Syrie	0.433	Grèce	0.423	Afrique du Sud	0.451
112	Slovaquie	0.444	Afrique du Sud	0.424	Syrie	0.462
113	Tadjikistan	0.460	Syrie	0.424	Pologne	0.481
114	Romanie	0.470	Bulgarie	0.429	Bulgarie	0.483
115	République tchèque	0.486	Chine	0.441	Rép. démoc. du Congo	0.500
116	Chine	0.502	Iran	0.441	Azerbaïdjan	0.501
117	Bulgarie	0.507	République tchèque	0.444	Estonie	0.502
118	Russie	0.524	Tadjikistan	0.467	Kirghizistan	0.507
119	Pologne	0.531	Irak	0.472	Iran	0.508
120	Azerbaïdjan	0.571	Pologne	0.473	Belarus	0.514
121	Arménie	0.587	Belarus	0.474	Chine	0.518
122	Belarus	0.594	Bosnie-et-Herzégovine	0.487	Bosnie-et-Herzégovine	0.533
123	Serbie	0.596	Estonie	0.494	Tadjikistan	0.549
124	Ouzbékistan	0.632	Moldavie	0.505	Moldavie	0.587
125	Estonie	0.639	Azerbaïdjan	0.527	Russie	0.590
126	Moldavie	0.643	Serbie	0.542	Irak	0.603
127	Kazakhstan	0.664	Russie	0.547	Serbie	0.628
128	Ukraine	0.665	Kazakhstan	0.598	Kazakhstan	0.652
129	Kirghizistan	0.725	Ouzbékistan	0.657	Ouzbékistan	0.706
130	Turkménistan	0.782	Ukraine	0.694	Ukraine	0.756
131	Mongolie	0.814	Mongolie	0.738	Turkménistan	0.786
132	Bosnie-et-Herzégovine	0.945	Turkménistan	0.825	Mongolie	0.814

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RELATION ÉNERGIE-ÉCONOMIE ET RÉGULATION ENVIRONNEMENTALE EN PRÉSENCE DE L'ÉCONOMIE NON ENREGISTRÉE

Cette thèse de doctorat comprenant cinq manuscrits et une brève analyse comparative internationale, propose une étude pluridisciplinaire sur les effets économiques et environnementaux de la consommation d'énergie. Elle étudie d'abord la relation de causalité entre la croissance économique et la consommation d'énergie en Turquie, puis offre une nouvelle méthodologie pour l'estimation de l'économie non enregistrée basée sur des données environnementales. La thèse développe également des modèles d'information asymétrique, où le régulateur ne connaît pas le véritable niveau d'émission de chaque entreprise qu'il souhaite réguler, afin d'examiner à quel point différents mécanismes de mise en application affectent incitations des firmes pour réduire leurs émissions polluantes et investir en technologies d'énergie propre. Afin de fournir un aperçu complet des effets des politiques de mise en application fiscale et environnementale, des analyses similaires ont été effectuées prenant en considération l'existence de l'économie non enregistrée. Les résultats montrent essentiellement que : premièrement, des politiques d'économies d'énergie peuvent être mises en application pour réduire les émissions de gaz à effet de serre sans effet nuisible sur les activités économiques enregistrées ; deuxièmement, différents mécanismes de contrôle doivent être employés selon l'objectif environnemental de l'agence d'application ; troisièmement, dans certains cas, les règlements environnementaux peuvent augmenter la taille de l'économie non enregistrée ; quatrièmement, la politique économique pour combattre l'économie non enregistrée peut ne pas servir de complément aux politiques d'économies d'énergie.

Mots-clés : Consommation d'énergie ; Economie non enregistrée ; Emissions de dioxyde de carbone ; Régulation environnementale

ENERGY-ECONOMY RELATIONSHIP AND ENVIRONMENTAL REGULATION IN THE PRESENCE OF UNRECORDED ECONOMY

This PhD thesis including five manuscripts and a brief international comparison analysis proposes a multi-field study on the economic and environmental effects of energy consumption. It first investigates the causal relationship between economic growth and energy consumption in Turkey and then offers a new methodology for the estimation of unrecorded economy based on environmental data. The thesis develops also asymmetric information models, where the regulator does not know the true emission level of each firm that it wishes to regulate, so as to examine to what extend different enforcement mechanisms affect incentives for the firms to reduce polluting emissions and to invest in clean energy technologies. In order to provide a complete insight on the effects of both fiscal and environmental enforcement policies, some similar analysis are conducted taking into account the existence of unrecorded economy. The results in this thesis essentially show that : first, energy conservation policies can be implemented in order to reduce greenhouse gas emissions without any adverse effect on the recorded economic activities ; second, different audit mechanisms should be used depending on the environmental objective of the enforcement agency ; third, in some cases, environmental regulations may increase the size of unrecorded economy ; fourth, economic policies to combat unrecorded economy may not serve as a complement to energy conservation policies.

Keywords : Energy consumption ; Unrecorded economy ; Carbon dioxide emissions ; Environmental regulation

Intitulé et adresse du laboratoire : Centre d'Economie de la Sorbonne (CES), Université Paris I Panthéonne-Sorbonne, Maison des Sciences Economiques, 106-112 Boulevard de l'Hôpital, 75647 Paris Cedex 13, France